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Preliminary Test Plan for Phase C/D

Volume II. Orbiter

Contract NAS9-10960
DRL M010, DRL Line Item 17
DRD TM002M
SD 71-105-2
25 June 1971

Space Division • North American Rockwell 12214 Lakewood Boulevard, Downey, California 90241

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SPACE SHUTTLE

PRELIMINARY TEST PLAN for Phase C/D

Volume II
Orbiter

Approved by

B. Hello
Vice President and General Manager
Space Shuttle Program

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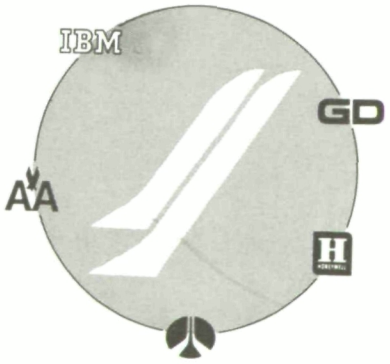

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FOREWORD

This plan is one of a family of program plans that establish, as applicable, requirements and prospective implementation approaches for the conduct of Phase C (Design) and Phase D (Development and Operations) of the Space Shuttle Program. With the exception of the cost data, which appear in the Cost and Schedule Estimates Plan only, each plan has been prepared in accordance with the specific contract requirements described in the Contract NAS9-10960 Statement of Work, Paragraph 4.7 and Appendix A, Data Requirements. These plans are as follows:

Title	Volume	SD No.	MSC No.
Program Management Plan for Phase C/D	One volume	SD 71-101	MSC-03308
Engineering and Development Plan for Phase C/D	I. Shuttle System II. Orbiter System III. Booster System	SD 71-102-1 SD 71-102-2 SD 71-102-3	MSC-03309
Operations Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster	SD 71-103-1 SD 71-103-2 SD 71-103-3	MSC-03310
Facility Utilization and Manufacturing Plan for Phase C/D	I. Orbiter II. Booster	SD 71-104-1 SD 71-104-2	MSC-03311
Preliminary Test Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster IV. Shuttle Support Equipment V. Shuttle Software	SD 71-105-1 SD 71-105-2 SD 71-105-3 SD 71-105-4 SD 71-105-5	MSC-03312
Logistics and Maintenance Plan for Phase C/D	One volume	SD 71-106	MSC-03313
Program Cost and Schedule Estimates Plan for Phase C/D	One volume	SD 71-107	MSC-03314

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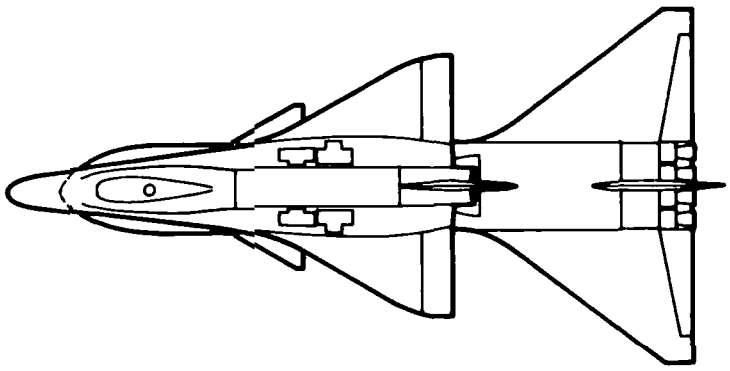
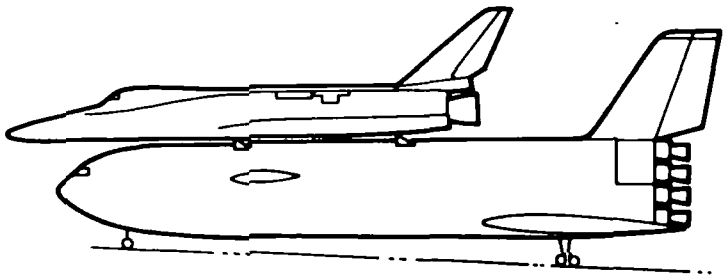
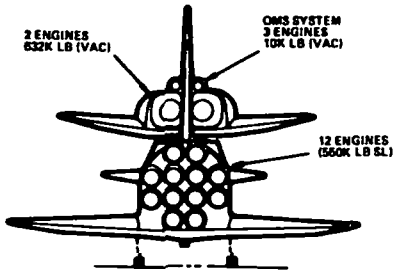
PREFACE

The objective of the Space Shuttle Program is to provide a low-cost space transportation system for placing and retrieving payloads in earth orbit. The first manned orbital flight is scheduled for April 1978. To achieve this goal, a reusable space shuttle system capable of a rapid turn-around, airline-type ground operation has been defined, satisfying as a minimum three basic missions: (1) 100-nautical-mile due-east circular orbit originating from a latitude of 28.5 degrees north, (2) a 55-degree inclination, 270-nautical mile earth orbit, and (3) a 100-nautical mile south polar circular orbit.

To accomplish these missions, a two-stage launch vehicle (shown below) has been defined, which is capable of delivering into orbit one stage with its payload. Each stage is capable of atmospheric entry and return to a designated landing site. The vehicle features moderate acceleration levels, a shirtsleeve cabin environment and quick turnaround capability. Operational facilities and system support equipment complement the flight vehicle.

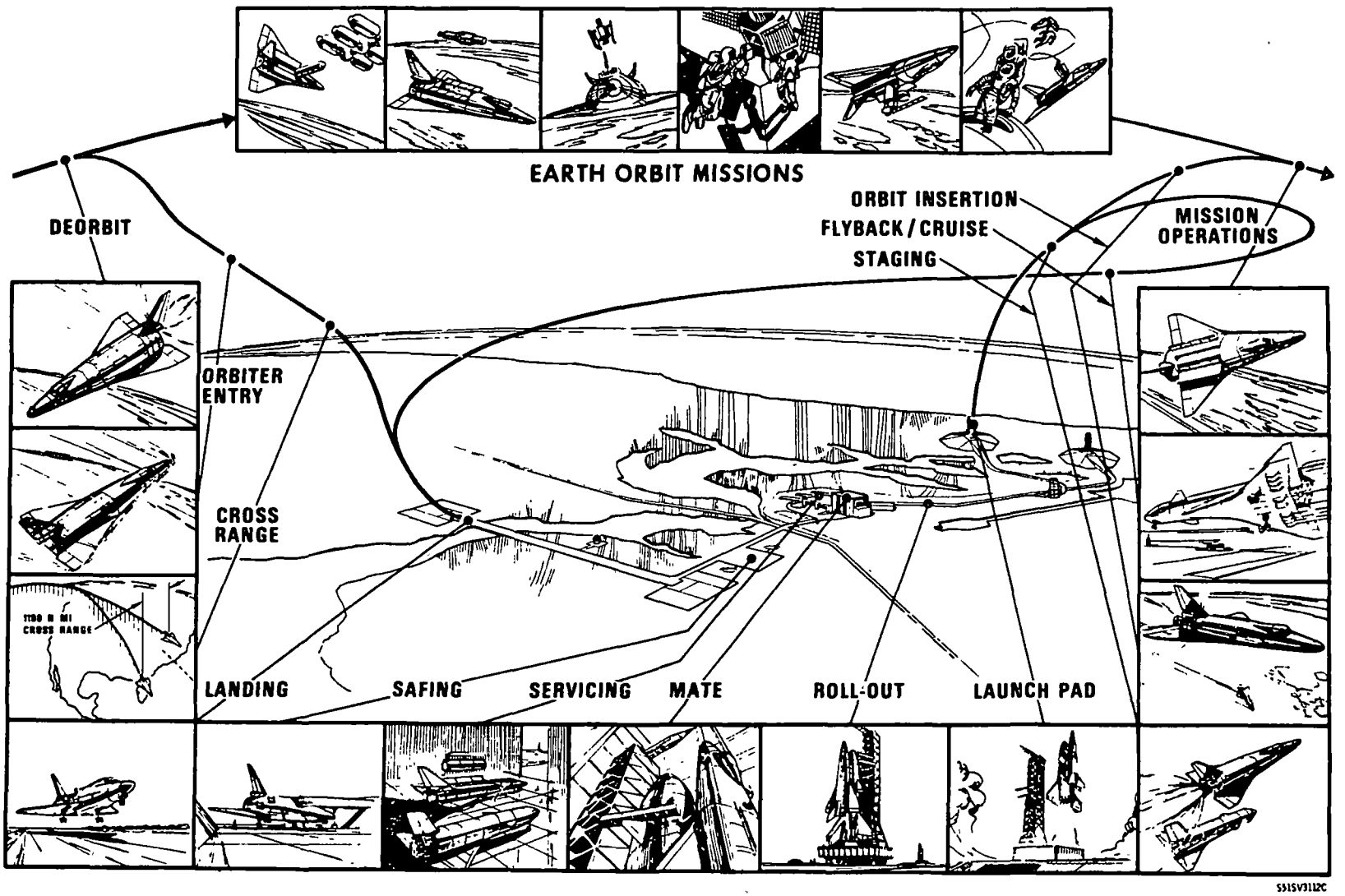






The booster and the orbiter are reusable delta-wing vehicles. The booster is equipped with 12 main rocket engines, an external heat shield to withstand the temperatures of boost and suborbital entry, and deployable airbreathing engines for cruising back to the launch site. The orbiter is equipped with two main rocket engines, orbital maneuvering rocket engines, an external thermal protection system to withstand the temperatures of boost and orbital entry, and deployable air-breathing engines installed for specific missions. The operations facility will provide for preflight readiness checkout, payload installation, and launch control, as well as primary landing sites and facilities for vehicle turnaround and necessary servicing. Shuttle support equipment includes all equipment required to check out, service, handle, and launch the flight vehicles.

The significant elements of these missions, as shown in the following figure, are ground operations, launch, and staging of the two vehicles. After staging, the first stage (booster) returns to the launch area while the second stage (orbiter) attains the prescribed insertion orbit after a series of orbital maneuvers. The second stage (orbiter) then delivers or retrieves its payload, enters the atmosphere, acquires the landing site, and completes the approach and landing. Safing operations are completed on each vehicle at the landing area preparatory to the turnaround cycle ground operations. Subsequent to payload installation in the orbiter, the orbiter is mated with the booster, and the mated system is made operationally ready and transported to the launch area for a new mission.



Elements of Space Shuttle Operations

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CONTENTS

Section		Page
1.0	PURPOSE	1-1
2.0	SCOPE	2-1
3.0	ORBITER TEST PROGRAM SUMMARY	3-1
	3.1 Subsystem	3-1
	3.2 Combined Subsystem	3-2
	3.3 Vehicle	3-5
4.0	TEST PHILOSOPHY AND CRITERIA	4-1
	4.1 Orbiter	4-1
	4.2 Subsystem	4-1
5.0	SUBSYSTEM TEST	5-1
	5.1 Main Propulsion Subsystem	5-4
	5.2 Auxiliary Propulsion Subsystem	5-17
	5.3 Air-Breathing Engine Subsystem	5-31
	5.4 Electrical and Mechanical Power Generation Subsystem	5-45
	5.5 Hydraulic Power Subsystem	5-59
	5.6 Guidance, Navigation, and Control Subsystem	5-76
	5.7 Data and Controls Management Subsystem	5-90
	5.8 Displays and Controls Subsystem	5-108
	5.9 Communication Subsystem	5-120
	5.10 Electrical Power Distribution and Control Subsystem	5-133
	5.11 Instrumentation Subsystem	5-143
	5.12 Environmental Control and Life Support Subsystem	5-153
	5.13 Flight Personnel Provisions, Human Factors Engineering, and Crew Escape Subsystem	5-171
	5.14 Body Structure	5-215
	5.15 Aerodynamic Surfaces	5-239
	5.16 Thermal Protection Subsystem	5-253
	5.17 Landing Subsystem	5-264
	5.18 Docking Subsystem	5-282
	5.19 Payload Deployment and Retrieval Subsystem	5-290
	5.20 Habitable Module	5-305

Section		Page
6.0	COMBINED SUBSYSTEM TESTS	6-1
	6.1 Cluster Firing Program	6-3
	6.2 Avionics/Nonavionics Test Program	6-17
	6.3 ECLSS/Crew Cabin Test Program	6-33
	6.4 Auxiliary Propulsion Subsystem Static Firing Program	6-44
	6.5 Wind Tunnel Test Program	6-56
	6.6 Integrated Thermal Control Subsystem	6-67
	6.7 Electromagnetic Compatibility	6-77
	6.8 Structural Dynamics Test Program	6-83
	6.9 Mockups and Simulation	6-93
7.0	VEHICLE TEST	7-1
	7.1 Orbiter Vehicle 1	7-1
	7.2 Orbiter Vehicle 2	7-43
	7.3 Orbiter Vehicle 3 and Subsequent Vehicles	7-43
	7.4 Support Requirements	7-45

ILLUSTRATIONS

Figure		Page
5-1	Main Propulsion Subsystem Elements	5-7
5-2	MPS Functional Schematic	5-8
5-3	MPS Test Logic and Constraint Network	5-13
5-4	MPS Test Schedule	5-14
5-5	Auxiliary Propulsion Subsystem Elements	5-20
5-6	APS Orbiter Schematic	5-21
5-7	APS Test Logic and Constraint Network	5-27
5-8	Preliminary APS Test Schedule	5-28
5-9	Air-Breathing Engine Subsystem Elements	5-34
5-10	ABES Fuel System Schematic	5-35
5-11	ABES Test Logic and Constraint Network	5-40
5-12	ABES Test Schedule	5-41
5-13	Power Generation Subsystem Elements	5-48
5-14	Power Generation Subsystem Schematic	5-49
5-15	Electrical/Mechanical Power Generation Test Logic and Constraint Network	5-56
5-16	Electrical/Mechanical Power Generation Test Schedule	5-57
5-17	Hydraulic Power Subsystem Elements	5-62
5-18	Hydraulic Power Subsystem Schematic	5-62
5-19	Hydraulic Power Subsystem Test Logic and Constraint Network	5-70
5-20	Hydraulic Power Subsystem Test Schedule	5-71
5-21	Guidance, Navigation, and Control Subsystem Elements	5-79
5-22	GN&C Subsystem Schematic	5-80
5-23	GN&C Test Logic and Constraint Network	5-86
5-24	GN&C Subsystem Test Schedule	5-87
5-25	Data and Control Management Subsystem Elements	5-95
5-26	DCM Hardware Schematic	5-96
5-27	DCM Test Logic and Constraint Network	5-99
5-28	DCM Subsystem Test Schedule	5-104
5-29	Avionics System Integration Laboratory Block Diagram	5-106
5-30	Displays and Controls Subsystem Elements	5-111
5-31	D&C Subsystem Schematic	5-112
5-32	D&C Subsystem Test Logic and Constraint Network	5-116
5-33	D&C Subsystem Test Schedule	5-117
5-34	Communications Subsystem Elements	5-123
5-35	Communications Subsystem Schematic	5-124

Figure		Page
5-36	Communications Subsystem Test Logic and Constraint Network	5-129
5-37	Communications Subsystem Test Schedule	5-130
5-38	Electrical Power Distribution and Control Subsystem Elements	5-135
5-39	Orbiter Baseline Electrical Power Distribution and Control Subsystem Schematic	5-136
5-40	EPD&C Test Logic and Constraint Network	5-139
5-41	EPD&C Subsystem Test Schedule	5-140
5-42	Instrumentation Subsystem Elements	5-145
5-43	Instrumentation Subsystem Schematic	5-146
5-44	Instrumentation Subsystem Test Logic and Constraint Network	5-149
5-45	Instrumentation Subsystem Test Schedule	5-150
5-46	Environmental Control and Life Support Subsystem Elements	5-157
5-47	ECLSS Subsystem Schematic	5-159
5-48	ECLSS Water and Pressurization Assemblies	5-160
5-49	ECLSS Test Logic and Constraint Network	5-166
5-50	ECLSS Test Schedule	5-167
5-51	Flight Personnel Subsystem Elements	5-175
5-52	Flight Personnel Subsystem Test Logic Network	5-181
5-53	Flight Personnel Subsystem Test Schedule	5-182
5-54	Human Factors Engineering Testing Subsystem Elements	5-190
5-55	Human Factors Engineering Test Logic	5-193
5-56	Human Factors Engineering Test Schedule	5-194
5-57	Crew Escape System Elements	5-204
5-58	Crew Escape System Test Logic Network	5-210
5-59	Crew Escape System Capabilities	5-211
5-60	Crew Escape System Test Schedule	5-212
5-61	Delta-Wing Orbiter Structural Arrangement	5-222
5-62	Body Structure Elements	5-223
5-63	Mid-Body Structure Elements	5-224
5-64	Delta-Wing Orbiter Forward Body	5-225
5-65	Nose Wheel Compartment Titanium Structure	5-226
5-66	Crew Compartment Key Structure	5-227
5-67	Mid-Body Delta-Wing Orbiter	5-228
5-68	Delta-Wing Orbiter Main Engine Compartment	5-229
5-69	Body Structure Test Logic Constraint Network	5-234
5-70	Body Structure Test Schedule	5-235
5-71	Delta-Wing Structural Arrangement	5-243
5-72	Vertical Surface Delta-Wing Orbiter	5-244
5-73	Aerodynamic Surfaces Elements	5-245
5-74	Aerodynamic Surfaces Test Logic Constraint Network	5-248

Figure		Page
5-75	Aerodynamic Surfaces Test Schedule	5-249
5-76	Wing Leading Edge	5-258
5-77	REI Block I/Block II Attach	5-259
5-78	Constraint Test Network	5-261
5-79	Thermal Protection System Phase C/D Schedule	5-262
5-80	Landing System Elements	5-269
5-81	Landing System	5-270
5-82	Nose Gear Installation	5-271
5-83	Main Gear Installation	5-272
5-84	Deceleration Parachute Subsystem	5-273
5-85	Landing Subsystem Test Logic and Constraint Network	5-278
5-86	Landing Subsystem Test Schedule	5-279
5-87	Docking Subsystem Elements	5-284
5-88	Orbiter-to-Orbiter Docking Sequence	5-285
5-89	Docking Subsystem Test Schedule	5-287
5-90	Payload Deployment and Retrieval System Elements	5-294
5-91	Docking and Cargo Handling System	5-295
5-92	Applicability of Manipulator Arms for Deployment and Retrieval	5-295
5-93	Personnel Transfer Port	5-297
5-94	Payload Retention	5-299
5-95	Payload Deployment and Retrieval Test Schedule	5-302
5-96	Habitable Module Structure	5-307
6-1	Test Vehicle Configuration Elements	6-7
6-2	Main Engine Cluster Firing Schematic	6-8
6-3	MPS Cluster Firing Test Schedule	6-14
6-4	Avionics Subsystems Integration Laboratory Configuration Elements	6-21
6-5	ASIL Schematic	6-23
6-6	ASIL Test Schedule	6-28
6-7	ECLSS/Crew Cabin Test Article Configuration Elements	6-35
6-8	ECLSS/Crew Cabin Laboratory Schematic	6-36
6-9	ECLSS/Crew Cabin Test Program Schedule	6-40
6-10	Test Article Configuration Elements	6-46
6-11	APS Static Firing Test Article Schematic	6-47
6-12	APS Static Firing Test Schedule	6-52
6-13	Summary SSV Phase C/D Wind Tunnel Test Schedule	6-64
6-14	Summary of Phase B Wind Tunnel and Related Test Programs Schedule.	6-65
6-15	Integrated Thermal Control of Orbiter	6-71
6-16	Integrated Thermal Control System Test Logic and Constrain Network	6-72
6-17	Integrated Thermal Control System Test Schedule	6-74
6-18	Electromagnetic Compatibility Test Logic Diagram	6-82

Figure		Page
6-19	Structural Dynamics Test Logic and Constraint Network	6-91
6-20	Structural Dynamics Test Schedule	6-92
7-1	Orbiter 1 Schedule	7-16
7-2	Test Flow Logic Diagram (Orbiter Final Assembly and Integrated Subsystem Acceptance Checkout)	7-26
7-3	Orbiter Vehicle 1 Preflight Ground Tests Schedule	7-34
7-4	Orbiter Vehicle 1 Horizontal Flight Test Schedule	7-39
7-5	Orbiter Vehicle 1 Flight Test Schedule, Stability and Control and Handling Qualification	7-40
7-6	Orbiter Vehicle 1 Flight Test Schedule, Performance	7-41
7-7	Orbiter Vehicle 1 Flight Test Schedule, ABES Propulsion	7-41
7-8	Orbiter Vehicle 1 Flight Test Schedule, GN&C	7-42
7-9	Orbiter Vehicle 1 Flight Test Schedule, Subsystem Performance	7-42
7-10	Orbiter Vehicle 1 Flight Test Schedule, Structures	7-42
7-11	Orbiter 2 Flow Schedule	7-44

TABLES

Table		Page
3-1	Test Article Hardware Requirement Summary	3-7
3-2	Ground Program Test Article Descriptions	3-10
4-1	Functional Criticality	4-4
5-1	Main Propulsion Subsystem Certification Requirements	5-9
5-2	MPS Test Article Requirements	5-15
5-3	MPS Test Support Requirements	5-16
5-4	Auxiliary Propulsion Subsystem Certification Requirements	5-22
5-5	APS Assembly Test Hardware Requirements	5-29
5-6	APS Test Support Requirements	5-30
5-7	Air-Breathing Engine Subsystem Certification Requirements	5-36
5-8	ABES Test Hardware Requirements	5-42
5-9	ABES Test Support Requirements	5-43
5-10	Power Generation Subsystem Certification Requirements	5-50
5-11	Test Article Requirements for Electrical and Mechanical Power Generation Subsystem	5-58
5-12	Hydraulic Power Subsystem Certification Requirements	5-63
5-13	Test Location Summary for Hydraulic Power Assemblies	5-72
5-14	Hydraulic/Controls Laboratory Test Article Requirements	5-73
5-15	Hydraulic Power Subsystem Test Support Requirements	5-74
5-16	Guidance, Navigation, and Control Subsystem Certification Requirements	5-81
5-17	GN&C Subsystem Test Hardware Requirements	5-88
5-18	GN&C Subsystem Test Support Requirements	5-89
5-19	Preliminary Allocation of Functions, Ground Versus On-Board Operations	5-97
5-20	Data and Controls Management Subsystem Certification Requirements	5-100
5-21	DCM Subsystem Test Article Requirements	5-105
5-22	DCM Subsystem Test Support Requirements	5-107
5-23	Displays and Controls Certification Requirements	5-113
5-24	D&C Test Hardware Requirements	5-118
5-25	D&C Test Support Requirements	5-119
5-26	Communication Subsystem Certification Requirements	5-125

Table		Page
5-27	Communication Subsystem Test Hardware Requirements.	5-131
5-28	Communication Subsystem Test Support Requirements .	5-132
5-29	Electrical Power Distribution and Control Subsystem Certification Requirements	5-137
5-30	EPD&C Subsystem Test Hardware Requirements . .	5-141
5-31	EPD&C Subsystem Test Support Requirements . . .	5-142
5-32	Instrumentation Subsystem Certification Requirements	5-147
5-33	Instrumentation Test Hardware Requirements . . .	5-151
5-34	Instrumentation Test Support Requirements . . .	5-152
5-35	Environmental Control and Life Support Subsystem Certification Requirements	5-161
5-36	ECLSS Test Hardware Requirements	5-168
5-37	ECLSS Test Support Requirements	5-169
5-38	Flight Personnel Subsystem Certification Requirements	5-176
5-39	Test Article Requirements - Flight Personnel Provisions	5-183
5-40	Support Requirements - Flight Personnel Provisions .	5-184
5-41	Human Factors Engineering Certification Requirements	5-191
5-42	Test Article Requirements - Human Factors Engineering Testing	5-195
5-43	Support Requirements - Human Factors Engineering Testing	5-197
5-44	Crew Escape System Certification Requirements . .	5-205
5-45	Test Article Requirements - Crew Escape System . .	5-213
5-46	Support Requirements - Flight Personnel Provisions .	5-214
5-47	Body Structure Subsystem Certification Requirements	5-230
5-48	Body Structure Subsystem Test Article Requirements .	5-236
5-49	Body Structure Subsystem Test Support Requirements .	5-237
5-50	Aerodynamic Surfaces Certification Requirements . .	5-246
5-51	Aerodynamic Surfaces Test Article Requirements . .	5-250
5-52	Aerodynamic Surfaces Structural Test Support Requirements	5-251
5-53	Thermal Protection Subsystem Certification Requirements	5-260
5-54	TPS Test Article Requirements	5-263
5-55	TPS Test Support Requirements	5-263
5-56	Landing Subsystem Certification Requirements . . .	5-274
5-57	Landing Subsystem Test Hardware Requirements . .	5-280
5-58	Landing Subsystem Test Support Requirements . . .	5-281
5-59	Docking Subsystem Certification Requirements . . .	5-286

Table		Page
5-60	Docking Subsystem Test Hardware Requirements	5-288
5-61	Docking Subsystem Test Support Requirements	5-289
5-62	Payload Deployment and Retrieval Subsystem Certification Requirements	5-300
5-63	Payload Deployment Subsystem Test Hardware Requirements	5-303
5-64	Payload Deployment and Retrieval Test Support Requirements	5-304
6-1	Cluster Firing Program Combined Subsystem Certification Requirements	6-9
6-2	Main Engine Cluster Firing Test Hardware Requirements	6-15
6-3	Main Engine Cluster Firing Test Support Requirements	6-16
6-4	Avionics Subsystem Integration Laboratory Certification Requirements	6-24
6-5	ASIL Test Hardware Requirements	6-28
6-6	ASIL Test Support Requirements	6-31
6-7	ECLSS Combined Subsystem Certification Requirements	6-37
6-8	ECLSS/Crew Cabin Test Program Test Article Requirements	6-41
6-9	ECLSS/Crew Cabin Test Support Requirements	6-42
6-10	APS Combined Subsystem Certification Requirements	6-48
6-11	APS Static Firing Test Hardware Requirements	6-53
6-12	APS Static Firing Test Support Requirements	6-54
6-13	Wind Tunnel Certification Requirements	6-61
6-14	Wind Tunnel Test Categories	6-63
6-15	Candidates for Phase C/D Wind Tunnel Facility Use	6-66
6-16	Integrated Thermal Control Subsystem Test Article Requirements	6-73
6-17	Support Requirements for Ground Purge Thermal Conditioning Tests	6-75
6-18	Electromagnetic Compatibility Certification	6-80
6-19	Structural Dynamics Certification Requirements	6-89
7-1	Flight Test Requirements	7-2
7-2	Acceptance Checkout Requirements	7-20
7-3	Preflight Ground Certification Requirements	7-33
7-4	Subsonic Flight Test Detail Requirements	7-36
7-5	Horizontal Flight Test Program Facilities Requirements	7-51
7-6	Range Support Service Requirements	7-58

1.0 PURPOSE

The Orbiter Test Plan is the second volume of the five-volume Space Shuttle Preliminary Test Plan. It defines the orbiter test program; relates that test program to the test requirements delineated in the Orbiter Contract End Item Specification and the development test requirements definable during this phase; and identifies test flows and schedules. Facility, support equipment, and software requirements are also defined for orbiter development, qualification, and acceptance testing.

2.0 SCOPE

The Orbiter Test Plan describes the Phase C/D testing of the orbiter vehicle, orbiter subsystems and, where complexity of development demands and configuration definition allows, components and assembly testing. This plan for orbiter testing bridges the gap between the current on-going Phase B testing, and describes the test requirements to ready the vehicle for the mated orbiter/booster testing described in Volume I.

Section 3.0 presents a general summary of the orbiter program and sub-level orbiter hardware testing.

Test philosophy and criteria are presented in Section 4.0. These guidelines were used in shaping the rationale and approach for testing the orbiter and its associated elements.

Development, certification, and acceptance test requirements are described for each subsystem in Section 5.0. Major ground tests required to integrate a total subsystem and interface functionally dependent subsystems have been covered under Section 6.0, Combined Subsystem Tests. Total integration of all subsystems within the orbiter, including flight tests, is described in Section 7.0.

Although the development and verification of support equipment and software are described in Volumes IV and V, respectively, the integration of the support equipment and software with the orbiter is described in this volume.

3.0 ORBITER TEST PROGRAM SUMMARY

The test program for the orbiter is an outgrowth of the normal sequence of requirements. The orbiter mission dictates the functional and environmental requirements of design; from these, the verification requirements are defined and documented in the Orbiter Contract End Item Specification. The verification requirements are analyzed, and the test logic and constraints are prepared for each subsystem and the overall Shuttle Program. The test program, including approach and rationale, is then optimized to ensure that it is cost effective and that the orbiter vehicle is ready to perform the designated missions. This plan approaches the orbiter testing at three hardware levels: subsystem, combined subsystems, and vehicle.

3.1 SUBSYSTEM

Development testing, both by the vendor and contractor, will require close coordination between test and design functions. It will be sufficiently flexible to encourage functional efficiency and maintainability in design, cost effectiveness in material selection, and optimization of fabrication and nondestructive test and inspection techniques. Each development test and its results will be documented for analysis and retained for subsequent retrieval. These test data will include objectives, conditions, support, and hardware limitations relative to production equipment.

Qualification testing for functional Criticality I hardware will be performed at certified vendor or contractor laboratories or customer-approved test facilities. Test procedures will follow a standard format and will reference the system or CEI specification and the test logic and constraint network.

Each orbiter subsystem is presented as a separate subdivision of Section 5.0 and includes a description of the subsystem and its major functional elements, design issues and certification requirements, test logic and constraints network, test approach and rationale, and support requirements for the respective tests including software, facilities, and support equipment.

3.2 COMBINED SUBSYSTEM

Major tests for the integration of specific subsystems and their integration with interfacing subsystems are covered in more detail under Section 6.0 and are summarized in the following paragraphs.

3.2.1 MPS Cluster Firing Test Program

The cluster static firing of the two orbiter engines will provide for an evaluation of the integrated main propulsion system, including engines, tanks, plumbing, pressurization, avionics, and controls. Support equipment, facilities, procedures, and software will be verified during these tests. Fit and functional compatibility with interfacing subsystems such as structures and avionics will also be demonstrated. Some of the objectives of the test are to verify (1) the ability of the support equipment to precondition, pressurize, and inert the tanks, (2) cryogenic tank fill and drain, vent, and propellant management, (3) thrust vector control, (4) avionics control interface, and (5) acoustic environment predictions.

3.2.2 Avionics/Nonavionics Test Program

The data control and management (DCM) subsystem and its complementing software is integrated in the Avionics Subsystem Integration Laboratory (ASIL) with (1) the guidance, navigation, and control (GN&C) subsystem, (2) displays and controls (D&C), (3) communications (COMM), (4) instrumentation, and (5) nonavionics subsystem interfaces. Support equipment, procedures, and test and operational software will also be integrated in this laboratory. These tests, in conjunction with the integration tests on the flight vehicles, will preclude the need for a special shuttle integration vehicle.

3.2.3 Environmental Control and Life Support Subsystem (ECLSS) Test Program

The ECLS will be integrated with the crew cabin to perfect the controls and demonstrate the ability of the ECLSS to provide adequate cooling for the avionics equipment in the cabin and shirtsleeve environment for the crew. This test will evaluate the ability of the ECLSS to condition and distribute the cabin air, control temperature of the electronic equipment, and maintain proper O_2/N_2 balance. Support equipment, software, and DCM control integration with the ECLSS will be effected during this test.

3.2.4 APS Integrated Test Program

The auxiliary propulsion subsystem for orbit maneuvering, attitude control and mechanical power generation (APU) share a common propellant and pressurization system. Integration tests, including hot firings, will verify the subsystem performance. Cryogenic tanking will demonstrate the propellant system/support equipment ability to service and control propellants. Dry gimballing tests will be used to verify the capability for thrust vector control of the orbit-maneuvering propulsion subsystem.

3.2.5 Wind Tunnel Test Program

Wind tunnel testing will be conducted to obtain data for analysis and development of design criteria and for substantiation of analytically predicted performance and design environment. The Phase C/D wind tunnel test program has been planned as a continuation of the testing either accomplished or planned during Phase B. The main categories for wind tunnel testing are aerodynamics, heat transfer, and structural dynamic tests.

Aerodynamic wind tunnel tests will be conducted for individual orbiter as well as mated orbiter/booster configrations. Aerothermodynamic wind tunnel tests will initially employ paint models to determine constant temperature contours. Subsequently, larger scale thermocouple models will be used to acquire more detailed temperature and heating rate data. Structural dynamic wind tunnel tests will provide air vehicle design data and validate the analytical methods used to calculate dynamic response and flutter margins. Tests will include classical flutter, stall flutter/buffet, panel flutter, and aerodynamic noise.

Orbiter and booster dynamic models will be used both individually and in a mated configuration to study launch vehicle structural dynamics in other than the liftoff flight region.

3.2.6. Electromagnetic Compatibility (EMC) Test Program

Assurance of electromagnetic compatibility represents testing activity at all hardware levels from the component to the complete vehicle. During the initial development phase, tests will be performed on new subsystem equipment, and additional necessary tests will be conducted on off-the-shelf black boxes to identify their generation of, or susceptibility to, electromagnetic interference. The results of these tests will be used in establishing requirements for subsequent tests at the subsystem and combined subsystem levels. Electromagnetic compatibility will be verified and any corrections required will be made in the Avionics Subsystem Integration Laboratory, on the hydraulics test stand, and ultimately on the flight test vehicle.

Evaluation at vehicle level will be performed during integrated checkout and post-checkout in the final assembly area and during preflight operations.

3.2.7 Structural Dynamics

Structural dynamics tests are designed to investigate three primary areas; namely, aeroelasticity and dynamic loads, Pogo, and shock, vibration, and acoustics. The first-named includes tests to support analytical studies of flutter, static aeroelasticity, buffet, and a number of dynamic response phenomena. One of the major dynamic test programs is the ground vibration test on the flight vehicle to verify analytically determined vehicle modes and damping characteristics. Pogo testing involves a coupling of the structural subsystem with the main propulsion subsystem to obtain data for confirmation of analysis. Test data are also required to support Pogo suppression development. Model tests will provide initial insight into potential problems associated with liquid sloshing coupled with the LO_2 tank/fluid axial modes. Static firing tests of single and clustered engines will provide data on the behavior of the feedline, pump, and engine with and without a suppression device. Finally, flight test operations with the main propulsion subsystem will be instrumented to obtain data on any Pogo tendencies. Shock vibration, and acoustic test programs are planned to validate predicted dynamic environments and to determine response of local structure and equipment for confirmation of design criteria. Initial aerodynamic noise predictions are checked by wind tunnel model tests. Rocket engine noise and cruise engine noise will be measured in static firing tests of individual engines. Full-scale vehicle testing consists of cluster firings to confirm predicted noise levels and inflight measurements for other vibro/acoustic environments. Ultimately, shock spectra will be obtained during separation, ABES deployment, and landing.

3.2.8 Integrated Thermal Control (TCS)

Thermal control tests are designed to ensure that all vehicle components and subsystems are maintained within their allowable temperature ranges during all mission phases. The TCS testing falls into two major categories: thermal-vacuum tests and ground purge thermal conditioning tests. Since cost and facility considerations preclude performing a ground thermal-vacuum test of an entire orbiter, the approach adopted is to expose major vehicle compartments to thermal-vacuum environment to achieve sufficient confidence, and then rely on actual flight for final validation of the TCS. The criticality and complexity of the purge gas system require early evaluation tests to support analysis and to permit optimization of ducting design. The ground purge evaluation consists of overall supply and gas distribution tests and separate thermal purge testing

of major vehicle compartments, including the main LH_2 tank compartment, main LO_2 tank/turbo fan engine compartment, main landing gear compartment, and forward landing gear compartment.

3.3 VEHICLE

The first two of the five orbiters scheduled to be manufactured will be identified initially as flight-test vehicles. Upon completion of the flight-test program, both vehicles will be refurbished to attain operational status and be assigned to the operational inventory.

Each flight-test orbiter will be configured with development flight instrumentation (DFI) and a crew-escape subsystem. The subsonic flight envelope will be investigated primarily with Orbiter 1, and the mated orbital demonstration with Orbiter 2.

3.3.1 Orbiter 1

Upon completion of assembly, each subsystem will be functionally checked. This will be followed by an in-plant dry integrated acceptance checkout of all subsystems, where no propellants and reactants will be used. After the integrated checkout, the vehicle will undergo ground dynamics tests.

Prior to first flight combined systems performance will be verified under operating conditions approaching as closely as possible those to be encountered in flight. Static ground runs as well as taxi and braking tests will be required to adequately verify the operation of all systems prior to flight to the test site.

The test program for subsonic flight will evaluate the static and dynamic longitudinal and lateral/directional stability, trim, and orbiter performance with four airbreathing engines and in the ferry configuration with a fifth engine installed. Takeoff and landing performance, automatic and unpowered approaches, and landings will be tested. Flutter and vibration, and jet engine in-flight start characteristics will be investigated within the available flight envelope.

3.3.2 Orbiter 2

Orbiter 2 follows the same integrated checkout, preflight ground test, and ferry sequence of activities as Orbiter 1. The test program for horizontal subsonic flight is limited and will only supplement the Orbiter 1 subsonic flight program. This vehicle is readied for the first mated flight by (1) a static firing, (2) facility/support equipment/vehicle interface checks, and (3) orbiter-booster mating and checkout. The mated activities are described in Volume I.

3.3.3 Test Hardware Requirements

A significant amount of vehicle hardware is required to implement the ground portion of the test program. A preliminary assessment of the number of test articles has been made and is detailed in Sections 5.0 and 6.0 and summarized in Table 3-1. The table lists subsystem hardware for subsystem and combined subsystem tests. Items that are reusable within the ground test program are identified. The "Total" column summarizes requirements in the form of equivalent ship sets.

3.3.4 Test Article Descriptions

The test hardware listed in the preceding paragraph is used for buildup of test articles for the ground test program. A brief description of each major test article and its use is given in Table 3-2. The test articles are categorized by subsystem, and are discussed in detail in Sections 5.0 and 6.0.

Table 3-1. Test Article Hardware Requirements Summary

Hardware Sets	Total Equivalent Ship Sets	Subsystem Test: MPS	APS	ABES	Power Generator	Hydraulic Power	GN&C	DCM	D&C	Communications	EPD&C	Instrumentation	ECLSS	Flight Personnel	Body Structure	Aerosurface	Landing	Docking	Payload Deployment	Combined Subsystem Tests: TPS	Avionics/Nonavionics	TCS	APS	ECLS	Cluster
Main propulsion																									
Propellant feed	4 5	3 5																							1 0
Pressurization	3 0	2 0																							1.0
Engines	1 0																								1 0
Auxiliary propulsion																									
Tanks	5 0		4 0																				1 00		
Thrust vector control	1 0																						1 00		
Propellant feed & distrib	1 0		(1 0)◇																				1 00		
GG/heat exchanger/pump	1 0		(1 0)◇																				1 0		
Gaging	1 5																				50		1 0		
Pressurization	1 0		(1 0)◇																				1 00		
Engines - OMS	1 0																						1 00		
Engines - ACPS	6		0 10																				50		
Air-breather propulsion																									
Propellant feed	1.0			1 00																					
Tanks — Mains	4 0			4 0																					
Tanks — Ferry	3.0			3 0																					
Engines	0. 5			50																					
Deployment mechanism	1 0			1.00																					
Ferry kit	0. 25			0. 25																					
Power generation																									
APU/Exhaust	0. 40										1 0*〉										1 0*		25		
Batteries	3.0				1 0						1 0										1 0				
Hydraulic																									
Aero control	1 0					1.0																			
Rocket engine control	2.0					1.00																	.50		.50
Landing gear control	1 0																1 00								
Hydraulic power units	2. 5			25		1 00											.50						25		50
Engine deploy control	50			50																					
GN&C																									
Control drivers	2. 1					0 5	(1 0														1 00		3		3
IMU	1 0						1 0														1 0				
Star tracker	1 0						1 00														1 00				
Rate sensor	1 5						1 0														1 50				
Air data system	1 0						1 0)◇														1 0				

Note: Bracketed items are reused for combined subsystem tests

*Generator portion of APU only

Table 3-1. Test Article Hardware Requirements Summary (Cont)

Hardware Sets	Total Equivalent Ship Sets	Subsystem Test																	Combined Subsystem Tests					
		MPS	APS	ABES	Power Generator	Hydraulic Power	GN&C	DCM	D&C	Communications	EPD&C	Instrumentation	ECLSS	Flight Personnel	Body Structure	Aerosurface	Landing	Docking	Payload Deployment	TPS	Avionics/Nonavionics	TCS	APS	ECLS	Cluster
Body structure																									
Fwd — Forward body outer shell	0 75														0.75										
Fwd — Nose assembly	1 0														1 0										
Fwd — LH_2 forward skirt	3 0														2 0										1 0
Fwd — LH_2 tank	3 0														2 0										1 0
Fwd — Cabin and IVA tunnel	2 1														1 0					0 10			1 0		
Fwd — LH_2 aft skirt	2 0														2 0										
Mid — Body shell	3 0														2 0										1 0
Mid — LO_2 tanks	2 5														1 5										1 0
Aft — Thrust structure - MPS	3 0														2 0										1 0
Aft — Thrust structure - OMS	3 0														2 0										1 0
Aft — Body shell	3 0														2 0										1 0
Data and control management																									
Data management computer	2.5							(75													1 5				1.0
Mass memory	2 5							1 0													1 5				1 0
Data bus/acts	1 35					05		50)◊													1 0		10	10	10
Displays and controls																									
Lighting	4 5								(1 0					3 00							1 0			50	
Displays	1 5								1 0					25							1 0			.25	
Controls	1 5								1 0)◊					25							1 0			25	
Communications																									
Voice link	1 25									(1 0											1 0			25	
Data link	1 0									1 0											1 0				
RF link	1 0									1 0											1 0				
Aids	1 0									1 0)◊											1 0				
Electrical power distribution and control																									
Lighting	2 0										(1 0			100%							1.0				
Power conversion	1 0										1 0										1 0				
Power control	1 0										75										.75		10	05	10
Power distribution	1 25										1 0)◊										1 0		.10	05	10
Instrumentation																									
DFI	.75											(50%									50		10	.10	.05
OPS instruments	75											50%)◊									.50		10	.10	05

Note. ◊ Bracketed items are reused for combined subsystem tests.

Table 3-1. Test Article Hardware Requirements Summary (Cont)

Hardware Sets	Total Equivalent Ship Sets	Subsystem Test																	Combined Subsystem Tests					
		MPS	APS	ABES	Power Generator	Hydraulic Power	GN&C	DCM	D&C	Communications	EPD&C	Instrumentation	ECLSS	Flight Personnel	Body Structure	Aerosurface	Landing	Docking	Payload Deployment	TPS	Avionics/Nonavionics	TCS	APS	ECLS	Cluster
Environmental control and life support																									
Heat transport	1.9												50								.40			1.0	
Heat sinks	1.4												.50											9	
Atmospheric control	1 0																							1.0	
Humidity and CO_2 control	1.0																							1.0	
Cabin temperature control	1 0																							1.0	
Waste management	2.0													1 0										1.0	
Food management	2.0													1 0										1.0	
Water management	1.2													2										1 0	
Vehicle purge	2.1																							1.0	1 0
Ferry kit heat sink	1 0																					1.0		1.0	
Flight personnel																									
Furnishings	3 0													3 0											
Equipment	2 5													2 5											
Ejection seat	14 5													14 5											
Vehicle elements (sets)	5 75													5 75											
Aerosurfaces																									
Wing	1.0															1 0									
Vertical stabilizer	2.0															2 0									
Landing																									
Nose gear	2 0																2 0								
Main gear	1.0																1.0								
Deceleration chute	1 0																1 0								
Docking																									
Adapter tunnel	1 0																	1 0							
Separation	1.0																	1 00							
Payload deployment and retrieval																									
Manipulator	1 0																		1 0						
Controls	1 0																		1 0						
Jettison mechanism	1 0																		1 0						
Retention mechanism	1 0																		1 0						
Cargo access tunnel	1 0																		1 0						
Thermal protection subsystem	0 29														03	03				03		20			

Note: Bracketed items are reused for combined subsystem tests

Note: The hardware quantities identified are for subsystem and combined subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies

Table 3-2. Ground Program Test Article Descriptions

Subsystem	Test Article Description	Utilization
MPS	Buildup of propellant feed and pressurization assemblies	Determine cold flow dynamic response.
	Buildup of propellant feed, pressurization, and engine assemblies; performed at engine contractor facility using feed and pressurization hardware supplied by the orbiter contractor.	Verify pressurization, feed system, and engine dynamic compatibility.
	Static Firing test vehicle consisting of MPS LH_2 tank, midbody with LO_2 tanks, main engine compartment and engines, propellant feed and pressurization systems; elements of the EPD&C, instrumentation, hydraulic power, DCM and TCS are also present for support; vehicle compartment purge is also installed	MPS cluster firing a. Integrate all elements of MPS b. Verify propellant loading/unloading techniques c Check out tanks, lines and vehicle purge systems d Integrate MPS and support equipment e. Integrate MPS with avionics
APS	Buildup of tanks, propellant feed/gaging, turbopumps and pressurization, accumulators and thrusters.	Integrate major subsystem elements, less OMS
	Subscale tank assembly	O-G verification of APS tankage
	Static firing buildup of three OMS engines, three gas generator/heat exchanger/turbopump packages, one bank of ACPS thrusters, one APU and exhaust, propellant feed ducts, and pressurization assembly with supporting avionics and hydraulics	APS static firing a. Integrate all elements of APS b. Integrate APU with APS c Integrate APS and support equipment d Integrate APS with avionics
ABES	Static firing buildup of Two ABES engines, main tank, propellant feed, and selected deployment hardware	a Integrate all elements of ABES b Integrate ABES with support equipment
	Deployment fixture consisting of dummy engine and deployment hardware	Verify deployment system

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
E/M power generation	Battery assembly breadboard. Fuel Cell - PRSD Assembly (simulated fuel cells interfaced with PRSD for testing at PRSD subcontractor) APS static firing buildup with one APU, controls, and exhaust system. (Reference APS test article description)	Integrate batteries, charge and controls. Integrate fuel cells with reactant supply assembly. APS static firing a. Integrate APU with APS reactant supply assembly b. Integrate APU with support equipment c. Integrate APU with avionics.
Hydraulic power	(Hydraulics/Controls Laboratory) full scale layout of hydraulic subsystem supported by "iron bird" type structure Test article is located adjacent to avionics systems integration lab., and is connected to the latter facility for controls end-to-end tests. (Reference DCM test articles description.)	Integrate all elements of hydraulic subsystem. Integrate hydraulics with aero and rocket engine controls. Integrate hydraulics with support equipment. Integrate hydraulics, controls and avionics (end-to-end).
G/N&C	Breadboard of subsystem with elements of D&C and DCM for support and computer simulation of other elements; this hardware will be reused for ASIL combined subsystem testing.	Develop and evaluate guidance, navigation, and flight control techniques. Evaluate software.

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
DCM	Breadboard of DCM consisting of one to three central processors, a complete main memory, one mass storage unit, and a percentage of the ACTS and data bus harness; elements of the D/C will be present for support; special utility software as well as early versions of the flight program executive will be used for subsystem operation; this hardware will be reused for ASIL combined subsystem tests.	Integrate data management computer mass memory, data bus and executive software. Verify performance of data management computer. Develop and refine subsystem operating techniques. Develop airborne and ground software. Integrate DCM with support equipment and software.
DCM (integrated avionics)	Avionics Systems Integration Laboratory,(ASIL) Laboratory buildup of all avionics subsystems consists of flight deck mockup containing displays and controls and avionics compartments and bays containing the DCM, EPD&C, G/N&C, COMM and Instrumentation; computer and/or hardware simulates non-avionics subsystems such as MPS, ECLSS, etc ; test article is designed to be interfaced with the hydraulics/controls laboratory, for flight controls end-to-end testing; special purpose and actual flight and ground software is included for operation of the test article; a portion of the ECLSS coldplate networks will be present for equipment cooling.	Integrate all avionics subsystems Integrate avionics with non-avionics subsystems Develop software Control systems end-to-end tests. Integrate avionics with support equipment.

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
COMM	Breadboard of subsystem with engineering model or prototype black boxes; DCM, D&C and other interfaces will be simulated; a ground station will provide artificial stimuli, signal demodulation and analysis as required. Black box elements of the subsystem will be reused during combined system testing.	Verify subsystem black box compatibility. Evaluate COMM and RF navigational techniques.
	Subscale models of shuttle vehicles in the mated and unmated configurations with scaled antenna installations for use on an antenna modeling range.	Verify adequacy of antenna placement for mated and unmanned configurations.
EPD&C	Breadboard of electrical power distribution conversion and control systems with simulated loads and simulated faults. Fuel cell power will be simulated while APU 400 Hz power will be derived from APU generators driven by facility prime movers. The laboratory will also furnish power to the integrated avionics during combined systems testing	Evaluate subsystem during fault simulation. Verify subsystem compatibility with electronic subsystem loads. Evaluate compatibility with subsystem controls (DCM, D&C).
Instrumentation	Partial breadboard of the DFI system will include prototype or engineering models of the black boxes. A ground station will enable demodulation and evaluation of subsystem outputs. The black box elements of the subsystem will be reused in the combined subsystems test article.	Verify subsystem black box compatibility. Verify multiplexing techniques. Evaluate DFI subsystem interfaces.
ECLSS	Breadboard of water and freon loop coldplate networks.	Develop coldplates; verification of flow rates and heat transfer rates.
	Space radiator, partial freon loops, freon pumps and controls, emplaced in a thermal-vacuum chamber.	Verify space radiator performance in vacuum environment. Integrate major assemblies of the ECLSS.
	Passenger, crew, avionics, and electronics compartments, containing all ECLSS assemblies, as well as selected items of the D&C, EPD&C, DCM, instrumentation, COMM, and flight personnel provisions and furnishings; thermal loads from the external environment as well as from the avionics and personnel will be simulated.	Integrate the ECLSS with support equipment. Integrate the ECLSS with elements of the DCM, D&C, EPD&C, COMM flight crew provisions/furnishings, and the body structure.

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
Flight personnel provisions	Separate buildups for structural tests of seats sleep restraints, emergency ground descent device, mobility and restraint devices and stowage containers.	Verify structural
Human factors	Breadboard layout of food management and waste management assemblies of the ECLSS	Evaluate human factors.
Crew escape system	Static firing setup of ejection seat, bulkhead, rails and catapult equipment, hatches and thrusters.	Qualify escape system
	Sled test setup of ejection seat, bulkhead, rails and catapult equipment, hatches and thrusters	Qualify escape system
Body structure	Static test article will include the forward, mid, and aft body sections including NLG supporting structure, doors, LH_2 tank and skirt structure, LO_2 tank and aft skirt structure, and engine thrust structure	Influence coefficient tests Verify body structure for critical design limit and ultimate loads. Verify NLG attachment structure for critical design limit and ultimate loads. Verify LO_2 and LH_2 tank structure for critical design limit and ultimate loads. Utilized as reaction structure for aerodynamic surface tests on wing/elevon and fin/rudder static test program. Verify structural adequacy and transmissibility of acoustic environment on mid-aft body sections Possible utilization for mated vertical GVT program

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
Body structure (Continued)	Fatigue test article will include the MLG attachment structure, LH_2 tank and skirt structure, mid and aft body sections, doors. LO_2 tank and skirt structure and engine thrust structure.	Verify body structure for critical fatigue spectrum loading to equivalent 400 flights. Verify MLG attachment structure for critical fatigue spectrum loading to equivalent 800 flights Verify LO_2 and LH_2 tank structure for critical fatigue spectrum loading to equivalent 400 flights. Utilized as reaction structure for aerodynamic surface tests on wing/elevon and fin/rudder fatigue test program.
	Cabin and IVA tunnel	Verify cabin and IVA tunnel structure for critical design limit loads Verify cabin and IVA tunnel structure for critical fatigue spectrum loading to equivalent 400 flights. Verify cabin and IVA tunnel for 1.1 times critical design loads with limit internal pressure followed by critical limit loads combined with 1.3 times limit internal pressure. Verify cabin structural adequacy and transmissibility of acoustic environment.
Aerodynamic surfaces	Static test sem-span wing/elevon, including MLG attachment structure and dummy stub wing.	Influence coefficient tests. Verify wing, elevon, elevon backup structure and MLG attachment structure for critical design limit and ultimate loads. Utilized as reaction structure for body static test program. Possible utilization for mated vertical GVT program

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Descriptions	Utilization
Aerodynamic surfaces (Continued)	Static test vertical stabilizer and rudder/speed brake.	Influence coefficient tests Verify vertical fin, rudder/speed brake, and rudder/speed brake backup structure for critical design limit and ultimate loads. Utilized as reaction structure for body static test program. Possible utilization for mated vertical GVT program
	Fatigue test sem-span wing/elevon, including MLG attachment structure and dummy stub wing	Verify wing, elevon and elevon backup structure for critical fatigue spectrum loading to equivalent 400 flights Verify MLG attachment structure for critical fatigue spectrum loading to equivalent 800 flights. Utilized as reaction structure for body fatigue test program
	Fatigue test vertical stabilizer and rudder/ speed brake	Verify vertical fin, rudder/speed brake and rudder/speed brake backup structure for critical fatigue spectrum loading to equivalent 400 flights. Utilized as reaction structure for body fatigue test program.
Thermal protection	Typical TPS panel configurations of RPP and REI for Block I and Block II designs. Will include curved and flat panels	Verify strain induced loading during body, wing and vertical stabilizer tests on critical panels. Verify structural adequacy of typical panels for critical design limit and ultimate loads and design environments Verify structural adequacy of typical panels for critical fatigue spectrum and environments to equivalent 100 flights.

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
Landing gear and deceleration	One nose and one main landing gear assembly, complete with doors, drag braces, gear and door locking mechanisms, actuator, hydraulic system, electrical control and indicator systems.	Metering pin development drop test program to obtain design efficiency of shock struts at design sinking speeds. Operational and endurance tests on NLG and MLG simulators for integrated system operational and functional verification of satisfactory wear life.
	One nose and one main landing gear assembly, complete with drag braces, actuators, and gear locking mechanisms	Verify NLG and MLG structural adequacy for critical fatigue spectrum loading to equivalent 800 flights.
	One deceleration parachute installation including backup structure, motar and release mechanism.	verify structural adequacy of parachute backup structure and release mechanism for critical design limit and ultimate loads. Verify functional operation of parachute, motor and release system after exposure to design environments
Docking	One docking adapter tunnel including latches and interface seals.	Verify functional adequacy of docking system and critical components previously exposed to critical mission environments. Verify structural integrity of docking adapter and automatic docking latches for critical design limit and ultimate loads.
	One docking separation system including actuators and latch release mechanism.	Verify functional adequacy of docking latch release mechanism and actuators after exposure to critical mission envirnoments. Verify structural adequacy of latch release mechanism for critical design limit and ultimate loads.

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
Payload deployment and retrieval	One ship set of PDRS manipulators (two assemblies), including booms, gear boxes, actuators, video and lights, and interface attach head	Verify functional operation of manipulator and control system for payload deployment and retrieval. Verify structural and functional adequacy of boom assemblies, interface attach head, gear boxes and actuators after exposure to mission environments.
	One ship set of PDRS controls, including manipulator operational and jettison control, manipulator and cargo stow lock release, transfer tunnel latch release and tunnel retraction.	Verify structural and functional adequacy of control systems for manipulator operation, jettison, stowage lock release cargo stowage lock release, cargo access tunnel latch release and tunnel retraction. Verify functional adequacy of actuators and critical components under applicable thermal and vacuum environment.
	One ship set of PDRS jettison mechanism, including actuators.	Verify structural and functional adequacy of manipulator jettison mechanisms. Verify functional adequacy of actuators and critical components under applicable thermal and vacuum environment.
	One ship set of PDRS retention mechanism, including cargo container stowage locks, manipulator stow locks and actuators.	Verify structural and functional integrity of stowage lock mechanisms for cargo container and manipulator. Verify functional adequacy of actuators under applicable thermal and vacuum environment.
	One cargo access tunnel assembly, including tunnel retract mechanism latches, actuators and seals.	Verify structural and functional adequacy of retractable tunnel and latch mechanisms. Verify functional adequacy of actuators, tunnel and seals under applicable thermal environments.

Table 3-2. Ground Program Test Article Descriptions (Cont)

Subsystem	Test Article Description	Utilization
Integrated thermal control	Breadboard of vehicle compartment purge installed in simulated orbiter vehicle.	Evaluate compartment purge system design.
	Section of orbiter midbody, containing simulated ABES engine.	Evaluate compartment venting.
	MPS cluster firing vehicle with vehicle purge system installed (reference MPS cluster firing)	Evaluate vehicle purge systems

4.0 TEST PHILOSOPHY AND CRITERIA

4.1 ORBITER

In addition to the test philosophy and criteria applicable to the total shuttle system, the following items are identified for the orbiter alone:

1. The first phase of flight testing will start after vehicle acceptance and will be limited to air-breathing-engine operations to demonstrate operational suitability and handling qualities for vehicle horizontal flight.

2. The air-breathing engine system (ABES) must demonstrate capability for performing with one engine out and for in-flight restart.

4.2 SUBSYSTEM

Subsystem test philosophy and criteria have been identified under three categories: development, qualification, and acceptance:

4.2.1 Development Testing

Development test criteria are as follows:

1. All development requirements will be satisfied by the maximum use of analysis and supported by development tests only as required.

2. When environmental testing is included in the development test program, the environmental levels will correspond to the most severe conditions anticipated for subsequent operational activity or testing.

3. Development testing of subsystems shall include verification of redundancy capability.

4. When the commonality items have been identified, the development test program will encompass the most severe requirements of either the booster or the orbiter.

5. Early subsystem integration with software will be a key test requirement.

6. Development tests may serve as qualification tests for functional Criticality I equipment in those cases where that action has a high probability of success and is cost beneficial.

7. Development of checkout and maintenance plans and procedures will be initiated during subsystem development and verified, along with operational procedures, during the flight test program.

8. Structural testing on major test articles will verify a satisfactory design margin. To reuse major structural test articles in subsequent test operations, destructive testing of major test articles will be minimized.

9. Acceptance test procedures, equipment, and test levels shall be proven and verified for subsequent use on flight equipment during the development testing phase.

10. Overstress testing, when required, may be conducted at the completion of the development program, utilizing the development hardware.

11. Data from EMC testing accomplished during the development program shall be utilized for compiling information for subsequent subsystem EMI susceptibility assessment.

12. Testing will be structured to provide initial information on maintenance final replacement, and projected service life requirements will be established during the operational test phase.

13. Hardware will be tested using operational fluids, gases, and lubricants. However, substitute media may be used when cost, facility, and/or safety limitations demand and the test requirements can be satisfied.

4.2.2 Qualification Testing

The principal criteria for qualification testing are noted below:

1. Hardware, the failure of which could result in loss of crew or vehicle, shall undergo qualification test for the environments specified. Environments selected shall be those that the hardware is expected to experience in its service life (ground and flight) plus the design margin. The environmental levels and durations will be the worst-case condition and will include the design margins.

2. Hardware, the failure of which would result in loss of primary or secondary mission objectives or in scrubbing launch shall be certified flightworthy on the basis of data accumulated from its test history during development, acceptance, off-limit, checkout, and flight test in lieu of rigorous qualification testing.

3. Qualification of components and subsystems will be based on the functional criticality of the system, as shown in Table 4-1.

4. Qualification testing requirements may be waived when equipment selected has been previously qualified to the level required for the proposed shuttle application. In these cases, adequate substantiation of configuration, inspection, facility certification, etc. must be submitted with supporting rationale to the contracting agency for approval of the waiver.

5. Qualification testing of components or subsystems will be accomplished at the highest practical level of assembly.

6. Qualification test levels must include verification of design safety factors.

7. Components which are to be subjected to qualification tests shall first be subjected to the same acceptance tests applied to flight components.

4.2.3 Production Assurance Test

Production assurance testing is part of the certification process for Criticality II and III items. The intent of these tests is to assure that production items are capable of performing their critical functions and withstanding their critical and sensitive environments and thus gain further confidence for flight worthiness. The test subjects at least one and not more than two production-accepted units to the most critical and sensitive

Table 4-1. Functional Criticality

Criticality	Potential Effect of Failure	Required Tests
I	A. Loss of life of crew member(s) (ground or flight). Also includes safety and hazard warning systems for primary operating systems whose failure has the potential of loss of crew members life. B. Loss of vehicle.	Certification by test data accumulation. Full qualification with rigorous testing.
II	A. Immediate (safe) termination of the mission flight or unscheduled termination at the next planned earth landing area. B. Loss of primary or secondary mission objectives.	Certification by test data accumulation. Selected items may undergo qualification testing with management approval.
III	Others	Certification by ground test data accumulation or flight certification

Note: Functional criticality is a loss of function due to a single stress or environment where redundancy due to its packing or location is negated. Determination of functional criticality requires FMEAs and knowledge of packaging and location (inboard profile).

environments and functions as determined from development tests and other data. The environmental levels and duration shall not exceed mission levels.

4.2.4 Acceptance Testing

Acceptance tests begin with vendor testing and continue through demonstration at the time of vehicle delivery and acceptance by the customer.

Manufacturing "In Process" Test Components/Subassemblies

1. Acceptance tests at the component/subassemblies level will provide the necessary quality inspection and testing rigor to assure that functional pre-installation testing will not be required. By exception only and with management approval, some items may undergo pre-installation testing due to accessibility, shelf life, or other factors.

2. For environmental-sensitive hardware, acceptance tests at the component/subassembly level must include specific environmental tests sufficient to screen defects. Criteria for selection of components and environments will be similar to those used on previous programs where proven effective.

3. Alternate or redundant path checkout will be a required component/subsystem feature.

Installed Subsystems

1. Subsystem-level tests will include a demonstration of all alternate and/or redundant paths, of operation, including malfunction switching logic, by exercising subroutines compatible with the on-board computer checkout and self-statusing capability.

2. Electromagnetic emission and/or susceptibility will have been determined initially at the subassembly (black box) level. Subsystem electromagnetic compatibility will be verified by performance checks during integrated checkout.

3. The on-board status and checkout capability, in conjunction with support equipment, will be used to perform installed subsystem acceptance testing.

4. Retesting shall demonstrate the integrity of the affected areas only.

5. Certifiable parts will be installed on the manufacturing line until such tests are successfully completed.

In-Process Checkout

The in-process phase of acceptance checkout, as expanded in Section 5.0, will include plumbing network structural integrity, cleanliness verification, and internal and external leakage checks; wire harness installation checks for continuity, insulation resistance, and high-potential verifications. Component acceptance checkout is governed by subcontractor acceptance checkout requirements. Component or subsystem installation checks are performed to the extent necessary to detect component or subsystem installation anomalies.

5.0 SUBSYSTEM TESTS

This section contains the certification requirements and the approach needed to satisfy the requirements for each orbiter subsystem. Specific items included in each subsystem section are as follows:

1. Subsystem Description
2. Certification requirements
3. Implementation method to satisfy requirement
4. Test logic and constraint network
5. Test approach and rationale
6. Test article requirements
7. Development test schedule
8. Support requirements (facilities, support equipment, and software)

A brief description of each subsystem is provided to establish a reference baseline configuration upon which certification requirements and test hardware are based. A subsystem hardware breakdown is also furnished which, in general, reflects the work breakdown structure (WBS) and established hardware levels.

Certification requirements are tabulated for each subsystem, with the method to be used to satisfy those requirements delineated as analysis or the test hardware level (i.e., model, component, assembly, subsystem, combined system or flight vehicle). These certification requirements have been grouped as development/qualification or in-process testing in Section 5.0 and vehicle level acceptance testing in Section 7.0. No attempt has been made to differentiate between development and qualification requirements, since under the current certification concept, qualification testing will be performed primarily on Criticality 1 hardware, and identification of all Criticality 1 items is beyond the scope of the Phase B study. The primary method for satisfying each requirement is identified with a "P" in the table of requirements. Those modes where additional data are derived to support the primary method are designated secondary and are identified with an "S".

To provide consistency in developing the test plan, the methods employed have been separated into the categories described below.

Category 1. Verified by engineering analysis. This includes design and technical analyses of a less formal nature than computer programming or mathematical modeling. Also included are engineering studies such as comparison of component characteristics and operational environment for qualification by similarity.

Category 2. Verified by computer program or mathematical model. This includes computer simulations and noncomputer mathematical model representations of the flight hardware and its interactions with the physical environment. These models and programs are usually constructed at the subsystem, combined subsystems, or vehicle level.

Category 3. Verified by component-level testing. This includes testing of individual components such as valves, regulators, lines, and black boxes.

Category 4. Verified by assembly-level testing. This includes testing of individual assemblies or combinations of two or more components from the same or different assemblies within a subsystem.

Category 5. Verified by subsystem testing. This includes testing of the complete subsystem or testing that involves a combination of elements of the subsystem. A subsystem is defined as level 5 of the WBS.

Category 6. Verified by combined subsystems testing. This includes testing that involves elements from two or more subsystems where the purpose of testing includes verification of interaction or interfaces of the subsystems. Typical examples are main propulsion cluster firing tests and avionics/nonavionics tests. Tests that include only ACT's or power/control cabling interfaces are not classified as combined subsystems tests.

Category 7. Verified by ground or flight test on the flight vehicle. This includes tests conducted in the mated or single-element mode during horizontal or vertical launched flights and preflight testing conducted on a flight vehicle, such as dynamic modes, taxi, and flight-readiness firings.

A test logic and constraint (TLC) network is developed from the tabulation of certification requirements and implementation methods. The network shows the level of testing from component through flight vehicle as well as the classification of testing (development, qualification, acceptance) and represents an initial top-level subsystem flow sequence. Since the Criticality 1 items have not been completely delineated during Phase B, qualification tests—for the most part have been arbitrarily located in the "component" column on the TLC networks. Subsequent definition of the Criticality 1 hardware items may result in qualification testing of some items at the assembly hardware level and beyond.

It is intended that the certification requirements, the TLC network, and accompanying approach and rationale summary cover the entire subsystem spectrum from component development through acceptance. Based on the constraints and flow sequence established in the TLC network, test article and subsystem development schedules are defined. The schedule and test article requirements establish additional requirements for test facilities and support equipment. The test article, facilities, support equipment, and required software are tabulated within each subsystem section. These data can subsequently be used for development of integrated test program schedules and for program cost data.

Acceptance testing at the vehicle level is described in Section 7.0. The in-process phase of acceptance testing covered in the subsystem sections consists of cleanliness verification and external-internal leak checks; verification of wire harness installation consists of bus isolation. insulation resistance, and high potential checkout. Component acceptance checkout will be a function of subcontractor acceptance requirements. Subsystem installation will be functionally verified to the extent necessary to detect and correct installation anomalies. Specific checkout peculiar to each subsystem is presented in the individual subsystem sections.

5.1 MAIN PROPULSION SUBSYSTEM (MPS)

5.1.1 Description

The MPS provides the required impulse to complete earth orbit injection of the orbiter vehicle following booster vehicle separation. The basic elements of the MPS include cryogenic propellant storage tanks, propellant pressurization and feed system, propellant gauging and management system, and two turbopump-fed LO_2/LH_2 rocket engines. The engine assembly is identical to that used on the booster vehicle with the exception that a two position (multiple expansion ratio) nozzle assembly is employed to achieve higher performance at altitude. A block diagram of the MPS is given in Figure 5-1 and a schematic diagram in Figure 5-2.

In flight, the respective propellant tanks are pressurized from GH_2 and GO_2 tapped from the engines. Tank pressure is controlled by gas flow regulation. Vehicle-supplied helium is used for pneumatic control and actuation of system components and engine pneumatic requirements. Ground-supplied helium is used for prelaunch pressurization.

The propellant feed ducts and the main propulsion engines are preconditioned before liftoff and during first-stage boost by operation of the engine low-pressure turbopumps. Normally open isolation valves with position latches are installed in each LO_2 and LH_2 feedline to provide emergency cutoff of propellant flow.

5.1.2 Requirements

MPS certification requirements, listed in Table 5-1 have been categorized by method of verification.

5.1.3 Approach and Rationale

To support component development and related subsequent requirements of the main propulsion subsystem, material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the main propulsion subsystem. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seals to function under mission requirements for temperature, pressure, loads, and exposure time.

2. Performance of thermal control coatings under long duration earth orbital exposure.

3. Compatibility of materials in contact with each other in environments which may result in a hazardous condition and/or degradation of properties.

4. Effects of structural and fluid system corrosion on useful life of critical materials.

5. Optimization of special welding techniques verified by mechanical and nondestructive tests.

6. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

7. Physical and mechanical properties of shuttle materials which have have not been previously established.

8. Development of materials accelerated life-test methods.

9. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly and assembly level. Subsystem and combined subsystem level ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6.

The test logic and constraint network for the MPS is given in Figure 5-3. Certification of the MPS will begin at the component level where most components will be subjected to critical environments (cryogenic shock and vibration) and durability testing to that extent required to assure a sufficiently high degree of success at the subassembly and assembly level. Concurrent with component development, development breadboard assemblies of the pressurization and propellant distribution systems will be tested to ascertain functional and dynamic response characteristics at the assembly level before interfacing with the space shuttle main engine (SSME).

Interface compatibility of the propellant distribution and pressurization systems with the SSME will be accomplished during development and qualification testing of the SSME by the SSME contractor. Testing will be accomplished under sea-level and simulated-altitude conditions. Overall MPS compatibility will be demonstrated during combined subsystem testing of the cluster firing test article (Section 6.1). During this testing phase,

initial support equipment interface compatibility and operational procedures verification will be obtained along with primary MPS interfacing subsystems compatibility, such as heat shield, electrical panel, gimbal actuators, and avionic engine recorders.

Final compatibility and capability of the MPS will be demonstrated during the flight test program, and verified for each flight article by static firing of the MPS before the first flight of each deliverable orbiter. A preliminary MPS development schedule is given in Figure 5-4.

5.1.4 Test Article Requirements

Preliminary MPS test hardware requirements to support assembly level testing are summarized in Table 5-2.

5.1.5 Support Requirements

Requirements for support of MPS tests are summarized in Table 5-3.

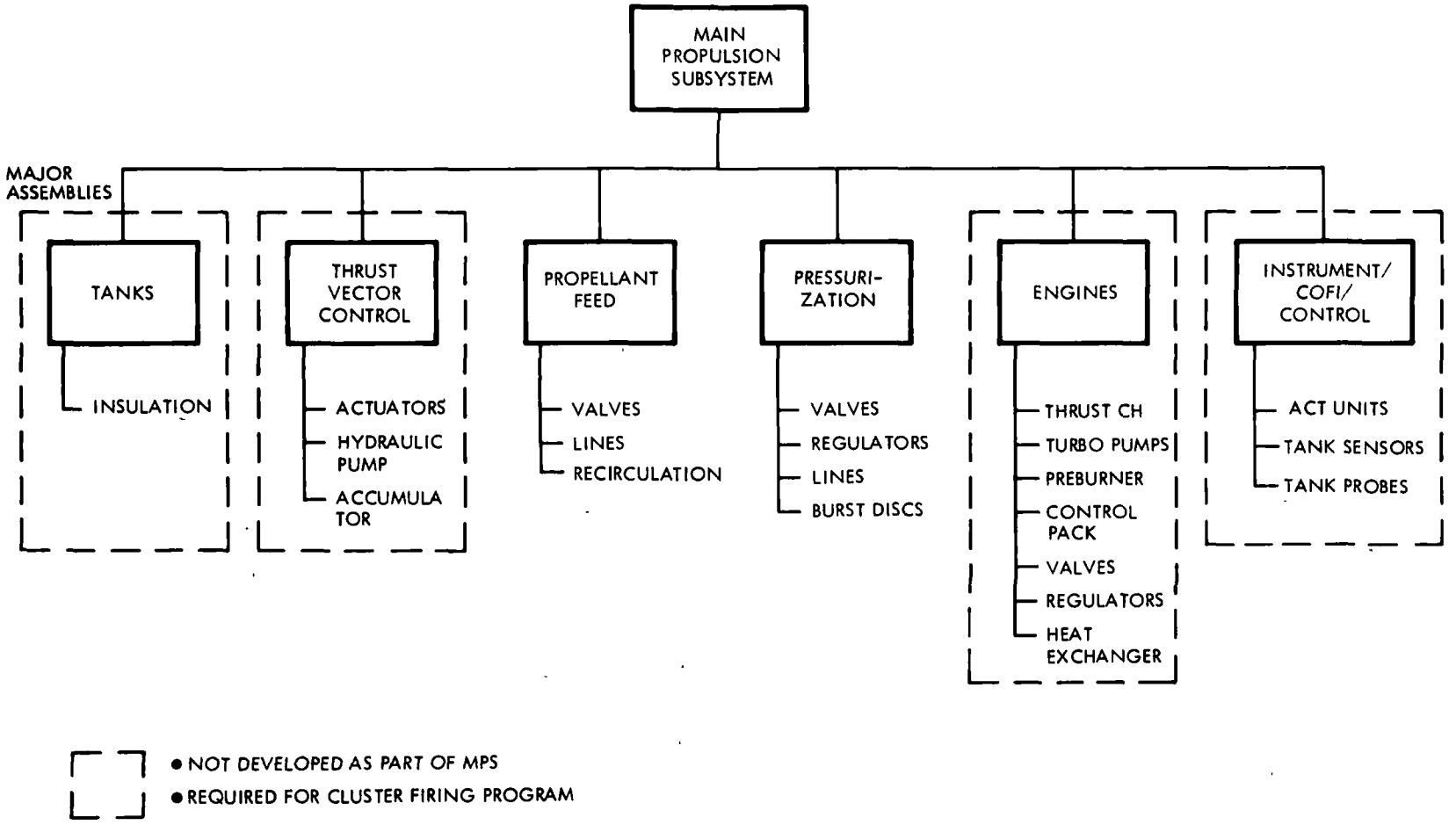


Figure 5-1. Main Propulsion Subsystem Elements

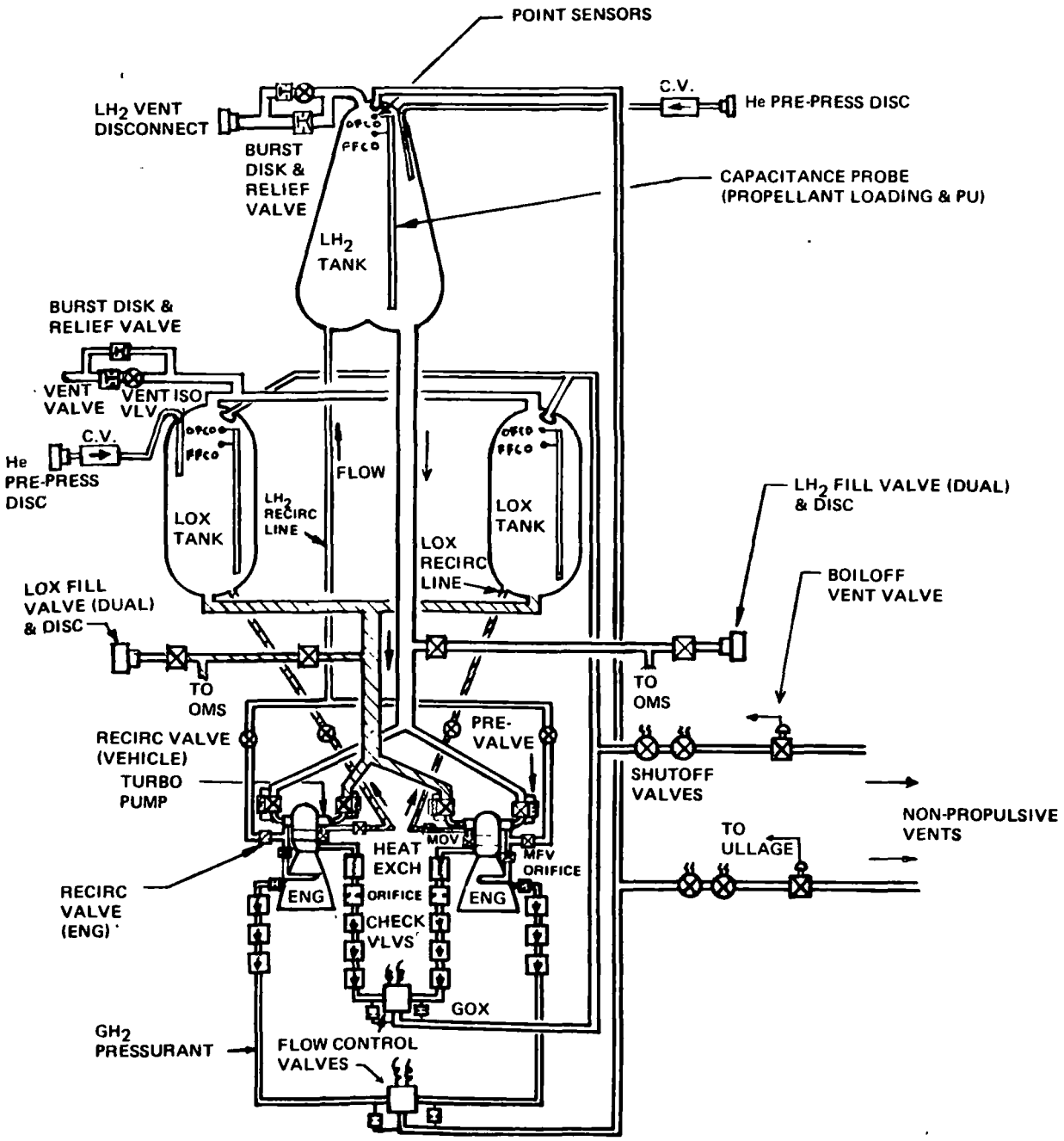


Figure 5-2. MPS Functional Schematic

Table 5-1. Main Propulsion Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
OPERATIONAL REQUIREMENTS							
1. Accessibility of components in mated and horizontal modes						S	P
2. Ability to horizontally change out engines						S	P
3. Ability to safe the main propulsion subsystem	S					P	S
4. Ability to engage and disengage all MPS umbilicals.			P			S	S
5. Ability of main propulsion subsystem to operate in one engine out mode					S	P	
6. Engine and engine compartment components ability to withstand acoustic and vibration environment	S				S	P	
7. Adequacy of base heating thermal protection for engine and engine compartment components	S				S	P	S
8. Ability of main propulsion subsystem to withstand boost environment	S	S					P
9. Ability to start engines in boost environment					S		P
10. Functional compatibility of main propulsion subsystem components at cryogenic temperatures	S	P	S				
11. Ability of engine to respond to crew initiated commands and to indicate response	S			S		P	S
ENGINE REQUIREMENTS							
1. Ability to dry gimbal with sufficient clearance	S					P	
2. Capability to dry gimbal engines in horizontal position				S		P	S
3. Ability to align engine thrust vector to orbiter center of gravity.	S					P	S
4. Ability to leak check engine/orbiter fluid and pneumatic interfaces						P	

Table 5-1. Main Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
5. Ability to perform leak test of engine high-pressure systems	S			P	S		
6. Functional ability to conduct engine sequence test				P	S		
7. Functional capability of propellant depletion/engine cutoff sequence	S					P	S
8. Capability of engine/vehicle Pogo supression	S				S	P	S
9. Ability to gimbal engines over angular rate and response range	S					P	
10. Ability to throttle engines over entire range (50 to 109 percent)			S			P	
11. Ability to extend and retract nozzle extension under flight loads	S			P			S
12. Ability to achieve satisfactory altitude engine start				P			S
13. Ability to inert the engine				P		S	
14. Adequacy of engine TVC attachment points to withstand loads (static, flight, landing)	S					P	
15. Capability to retract nozzle in abort modes	S			P			
16. Capability of MPS to supply the engine with required GN_2, GHe, electrical, and hydraulic services per the engine ICD requirements	S				S	P	
17. Ability to extend and retract nozzle during ground operations				P		S	
18. Maximum dry gimbal rate is within specification	S					P	
19. Ability of subsystem to withstand space environmental effects.	S		P	S			

Table 5-1. Main Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
PROPELLANT TANK AND FEED ASSEMBLY							
1. Ability to purge propellant tanks and feedlines				S		P	
2. Capability to monitor feedline vacuum condition			P	S		S	
3. Ability to provide propellants to engine under all operating conditions				S		P	
4. Capability of pre-valves to vent trapped propellant in engine back into tanks				S		P	
5. Results of propellant stratification on propellant residuals	S					P	
6. Boiloff rates of main propulsion subsystem	S					P	
7. Engine heat leak rate	S					P	
8. Capability of feed system to withstand dynamic, thermal and pressure requirements.	S			P		S	S
PRESSURIZATION ASSEMBLY							
1. Capability to inert pressurization assembly				S		P	
2. Capability of pre-pressurization assembly to provide adequate tank pressure through boost phase	S					P	
3. Ability of vent valves to maintain tank pressure			S			P	
4 Capability of pressurization assembly to provide pressurizing gas to propellant tank under all conditions				S		P	
PU ASSEMBLY							
1. Adequacy of point sensor and capacitance probes and point sensors to control propellant loading			S			P	
2. Compatibility of propellant quantity gauging system with propellant tanks	S					P	

Table 5-1. Main Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
3. Ability of PU assembly to provide within specification limits propellant flow rate			S			P	
4. Compatibility of capacitance probes and point sensors with vehicle IAS	S					P	
MISCELLANEOUS							
1. Ability of propellant recirculation assembly to condition the propellant feed lines and engines prior to engine start				S		P	
2. Capability of the helium supply to meet propulsion subsystem functions/requirements						P	
3. Compatibility of propulsion subsystem with COFI						P	
4. Compatibility of propulsion subsystem with instrumentation						P	
5. Structural integrity of slosh and antivortex baffles during fill, drain, and engine feed modes				S		P	
6. Acceptability of simultaneous LO_2 and LH_2 servicing						P	
7. Compatibility of propulsion subsystem with SE	S					P	
8. Capability to offload propellant at specified rate	S					P	
9. Ability to vent ullage pressure thru vehicle ground vent with back-pressure limits	S					P	
10. Ability to maintain positive tank pressure during ground operations				S		P	
11. Ability of overheat detection system to properly monitor engine compartment environment						P	S

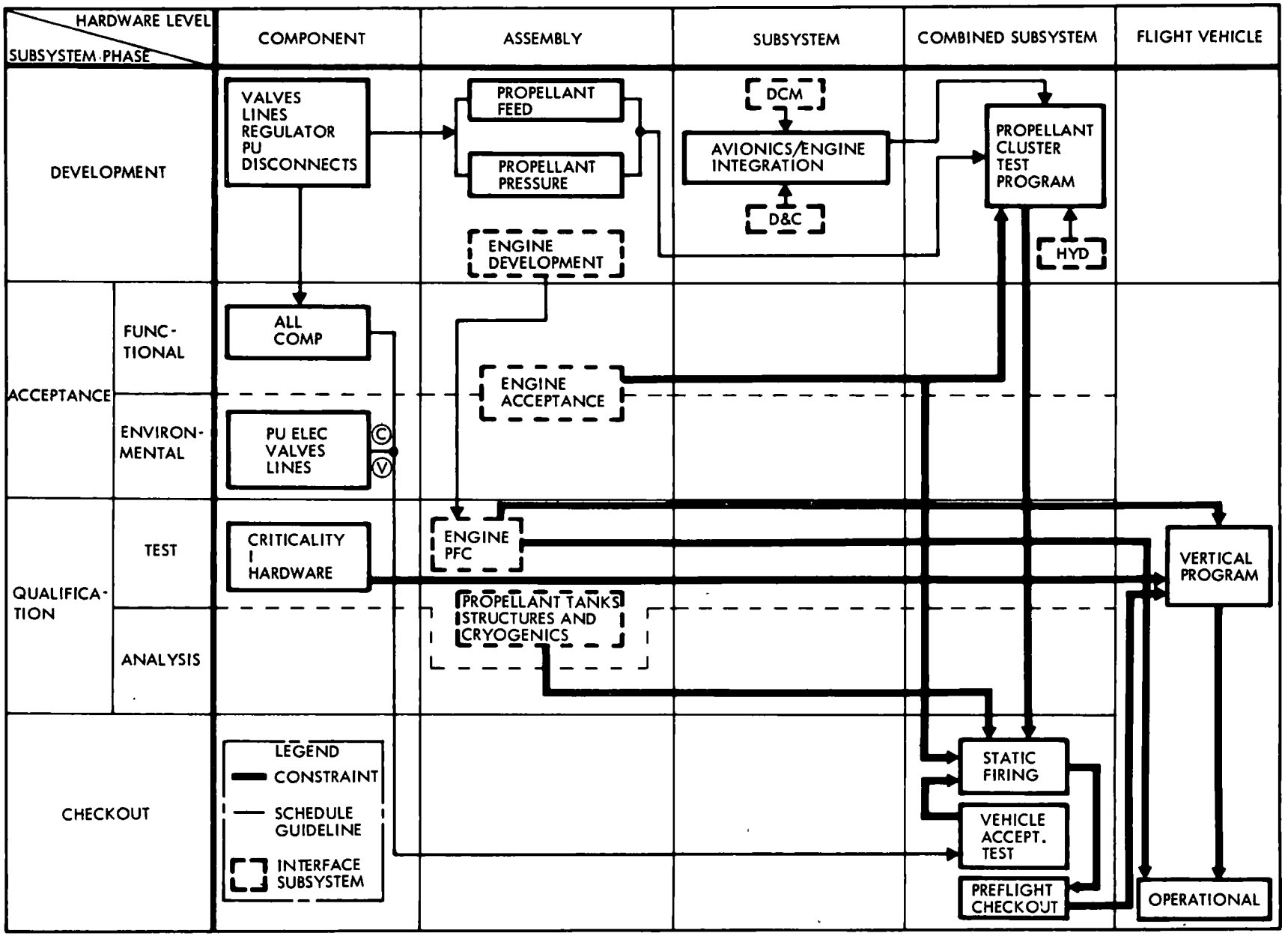


Figure 5-3. MPS Test Logic and Constraint Network

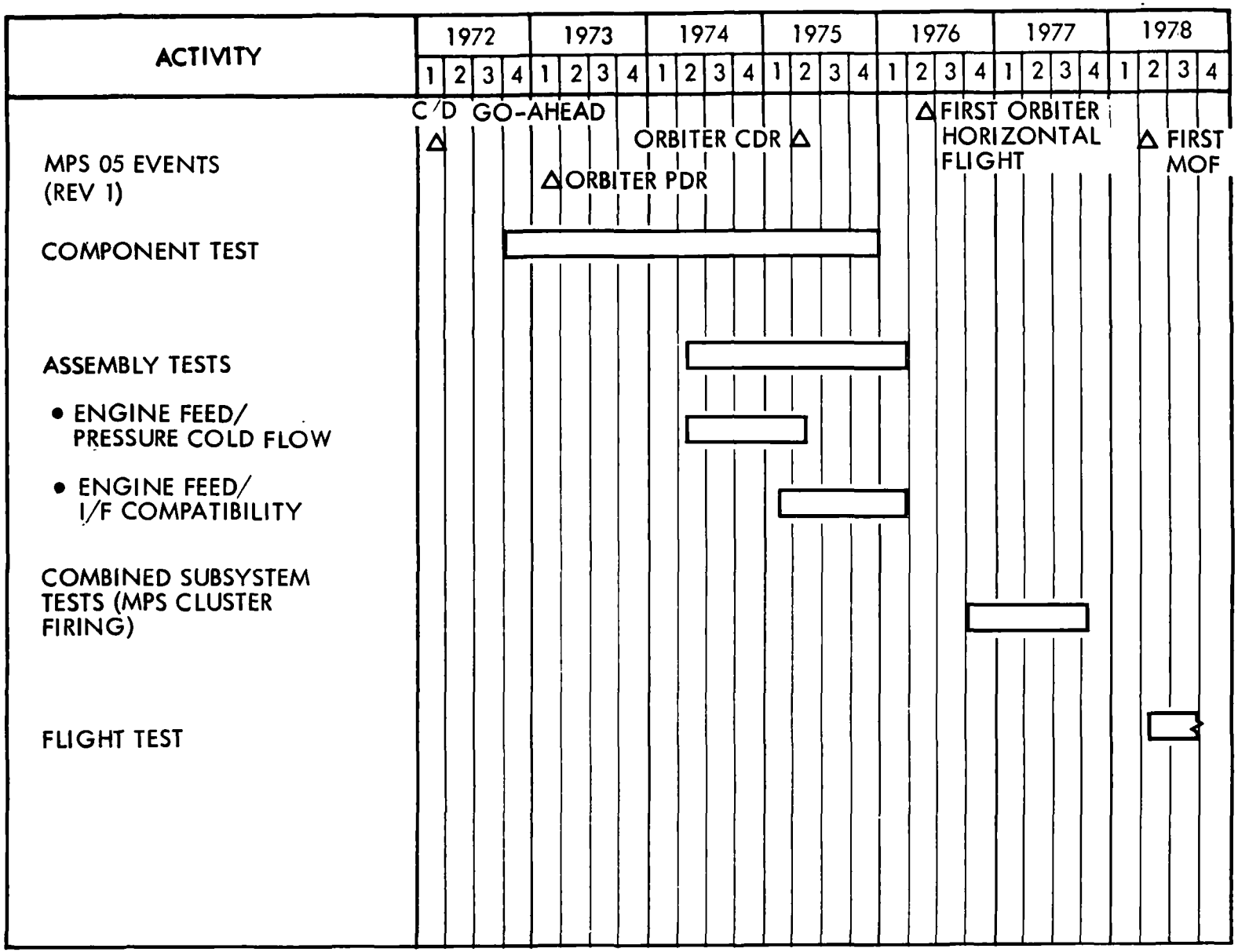


Figure 5-4. MPS Test Schedule

Table 5-2. MPS Test Article Requirements

Assembly	Quantity (percent)	
	Cold Flow Dynamic Response	Engine Interface Compatibility
Propellant feed and manifold (LO_2/LH_2)	150	200
Propellant pressurization	100	100
Helium system	-	100

Notes:
1. Since prototype hardware is to be employed, provision is made for replacement of components during the test program.
2. The quantities reflected include a single-engine set each for engine manufacturer sea level and simulated altitude testing.
3. The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.

Table 5-3. MPS Test Support Requirements

Item	Requirement
Facility	Electrical power 60 cycles three phase - 120 v, 440 v; 28 vdc Water - Firex, potable LO_2 storage/transfer GO_2 storage/transfer GN_2 storage/transfer LN_2 storage/transfer He storage/transfer H_2 disposal Structure to support cold-flow tests Test control room
Support equipment	Test gas distribution/regulation unit Test control console Flow measuring apparatus Miscellaneous environmental test equipment
Software	None

Note: The requirements identified are for cold-flow dynamic response testing of the propellant feed and pressurization assemblies, and do not reflect requirements for individual components or sub-assemblies or for engine interface compatibility testing contractor.

5.2 AUXILIARY PROPULSION SUBSYSTEM (APS)

5.2.1 Description

The auxiliary propulsion subsystem provides the capability for orbital maneuvers (i.e., three-axis translational maneuvers, three-axis attitude control, orbit circularization, orbit transfer, orbital rendezvous, and deorbit). The APS subsystem may be divided into two basic elements, an orbital-maneuvering propulsion system (OMS) and an attitude-control propulsion system (ACPS). The two propulsion system elements have a common cryogenic propellant source separate from that of the MPS. The subsystem includes ACPS thrusters, OMS engines, thermodynamic venting subsystem, regulators, control valves, heat exchangers, sensors, cryogenic tankage, gas generators, turbopumps and propellant accumulators. The accumulators also provide gaseous H_2 and O_2 to the auxiliary power units of the electrical/mechanical power generation subsystem.

The APS subsystem elements are presented in Figure 5-5, and a functional schematic is shown in Figure 5-6. The baseline OMS employs three LO_2/LH_2 rocket engines. Single engine operation is adequate for orbital maneuvers; however, all three engines will normally be operated simultaneously. The baseline ACPS employs 29 GO_2/GH_2 thrusters.

Propellants are stored in two LH_2 tanks and two LO_2 tanks. Each set is connected in series. The pressurization system uses gaseous oxygen and gaseous hydrogen bled from gas storage vessels (accumulators) for prepressurization and from the OMS engine during steady-state OMS operation. A thermodynamic venting system provides for zero-g venting with no liquid losses. The vent system employs LH_2 boiloff passed through regulating control valves and heat exchanger coils to subcool the LO_2 and absorb heat penetrating the LH_2 tank insulation. For adequate OMS propellant feed under zero-g conditions, pull-through and antivortex baffles, and self-wetting wire mesh capillary barriers are installed in the downstream LO_2 and LH_2 propellant storage tanks. Vehicle-supplied helium and electrical power are used for control and actuation of system components.

Thruster inlet pressure is controlled by individual pressure regulators located in each subsystem distribution network. Gas generators burning gaseous propellants extracted from the accumulators supply the heat for propellant conditioning.

5.2.2 Requirements

The auxiliary propulsion subsystem test requirements are delineated in Table 5-4 and are categorized by method of verification. The APS component level development/qualification/acceptance test requirements are included in Figure 5-7.

5.2.3 Approach and Rationale

To support component development and related subsequent requirements of the auxiliary propulsion subsystem, material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the APS. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seals to function under mission requirements for temperature, pressure, loads, and exposure time.

2. Performance of thermal control coatings under long duration earth orbital exposure.

3. Compatibility of materials in contact with each other in environments which may result in a hazardous condition and/or degradation of properties.

4. Effects of structural and fluid system corrosion on useful life of critical materials.

5. Optimization of special welding techniques verified by mechanical and nondestructive tests.

6. Physical and mechanical properties of shuttle materials which have not been previously established.

7. Joining methods for candidate alloys for shuttle structural and thermal requirements.

8. Development of materials accelerated life-test methods.

9. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, and/or assembly level. Subsystem and combined subsystem level ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6.

The APS test logic and constraint network is given in Figure 5-7. Certification of the APS will begin at the component level where most components will be subjected to critical environment and durability testing to

that extent required to assure a sufficiently high degree of success at the subassembly and assembly levels. Component testing will include valves, regulators and accumulators. Concurrent with the component development program, assembly-level testing of the OMS engine, ACPS thruster, LH_2 tank, LO_2 tank, accumulators and the propellant feed and conditioning system will be initiated. The OMS engine and thruster test programs are directed toward the development and qualification of these assemblies. The LH_2 tank program will use a subscale model to be tested in zero-g environment to evaluate and demonstrate the propellant gauging and thermal venting systems. A development breadboard assembly (using development and prototype hardware) of the propellant feed and conditioning system will be employed to evaluate feed response and performance characteristics.

Following the accumulation of sufficient test data at the assembly levels described above, higher assembly level testing of the propellant feed and conditioning system/OMS engine and an ACPS accumulator/feed system/engine will be accomplished to demonstrate interface compatibility of those major assemblies. Qualifiable hardware will be used for this series of testing. The ACPS accumulator/feed system/engine will be a development breadboard. The propellant feed and turbopump system will be integrated with engine supplier single-engine development and qualification testing at both sea-level and simulated-altitude conditions.

With the satisfactory progression of the above test programs, an APS (OMS/ACPS) test fixture will be employed to evaluate/demonstrate overall subsystem compatibility performance, and response characteristics. Single and multiple OMS engine and ACPS thruster firings will be performed individually and simultaneously.

Final APS combined subsystem compatibility and capability will be demonstrated through the acceptance test firing of the subsystem before first flight of each deliverable orbiter. A preliminary APS development schedule is presented in Figure 5-8.

5.2.4 Test Article Requirements

A preliminary list of APS hardware required for assembly-level testing is given in Table 5-5.

5.2.5 Support Requirements

Test support requirements are listed in Table 5-6.

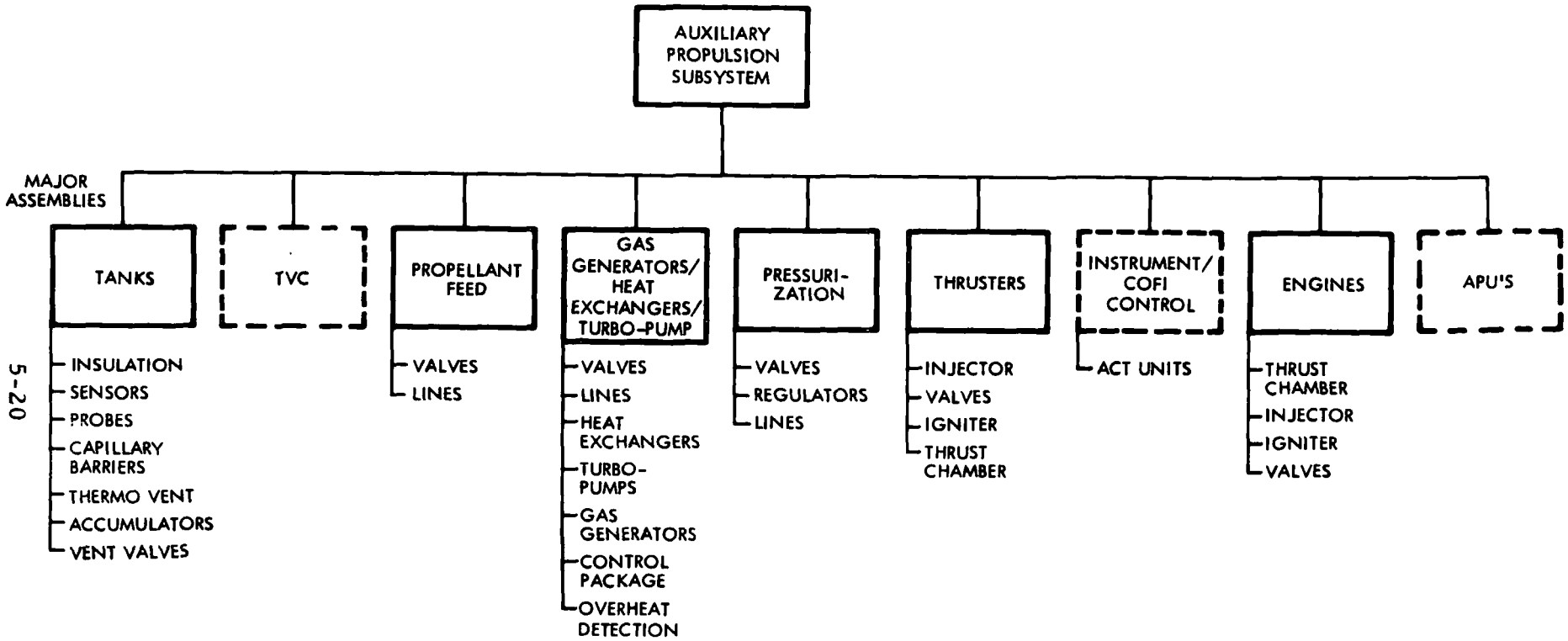


Figure 5-5. Auxiliary Propulsion Subsystem Elements

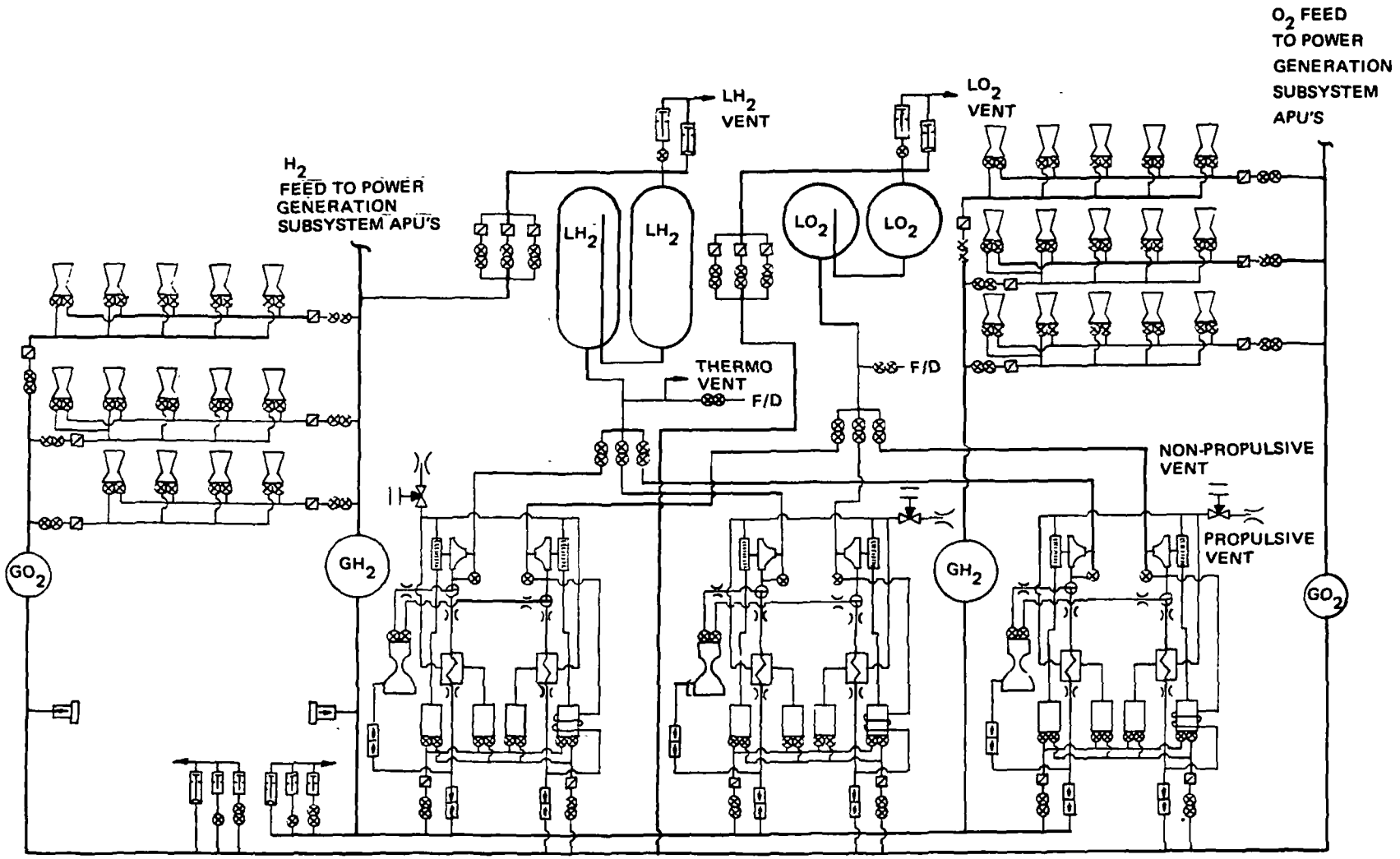


Figure 5-6. APS Orbiter Schematic

Table 5-4. Auxiliary Propulsion Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL							
1. Capability of subsystem to provide the required orbit maneuvering and attitude-control impulse	S		S			P	
2. Ability to activate subsystem prior to deorbit	S			S		P	S
3. Ability of subsystem to operate in zero g	S			S			P
4. Capability of subsystem to withstand vibration and acoustic effects from MPS operation	S		P	S			
5. Ability of subsystem to operate under all ground and flight conditions without structural and/or feed system coupling	S					P	S
6. Ability of subsystem to withstand space environment effects	S		S	S			P
7. Subsystem capability to withstand main propulsion engine base heating effects	S			S			P
8. Ability of overheat detection system to properly moniter combustion zone environment	S			S		P	
PROPELLANT PRESSURIZATION AND VENT ASSEMBLY (NORMAL AND THERMAL)							
1. Ability to maintain tank pressure	S			S	P		
2. Ability of thermodynamic vent to maintain LH_2 and LO_2 temperature within specified requirements	S			P			
3. Capability to pressurize the LO_2 and LH_2 tanks with the ground prepressurization	S		S		P		
4. Ability to service tanks in required time with ground vehicle/ GSE vent system	S		S			P	S
5. Engine-out performance				S	P		

Table 5-4. Auxiliary Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
PROPELLANT STORAGE AND FEED ASSEMBLY							
1. Capability of propellant retention screens to withstand flight environment	S			P			S
2. Capability of propellant tank structure to withstand flight environment	S			P			S
3. Ability of propellant retention devices to provide liquid at the pump inlets in zero g	S			P			S
4. Ability to provide propellant to the pump inlets at the required conditions (temperature and pressure) for ground and flight operations	S		S			P	
5. Compatibility of subsystem fill and main propellant servicing distribution line	S					P	S
6. Capability to drain tanks in vertical attitude	S					P	
7. Ability to drain tank residuals in horizontal attitude	S					P	S
8. Capability of retention screens to withstand propellant loading loads						P	S
9. Capability to monitor and evacuate vacuum jacketed feed lines						P	S
10. Ability to establish and maintain tank jacket vacuum				P		S	
PROPELLANT CONDITIONING AND DISTRIBUTION ASSEMBLY							
1. Ability of orbit maneuvering engines to provide GH_2 for attitude control motors, tank pressurization, and APU's.	S					P	
2. Capability of LO_2 turbopump heat exchanger auxiliary coils to provide GO_2 for attitude control motors, tank pressurization, and APU's	S					P	

Table 5-4. Auxiliary Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
3. Capability of assembly to provide inlet pressure at specified conditions and at specified response to the attitude-control thrusters and to the APU's	S			S		P	
4. Capability of H_2 and O_2 gas generators and heat exchangers assemblies to provide sufficient conditioned propellants for attitude-control thrusters, tank pressurization, turbopump, gas generator, APU, and ECLSS operations	S					P	
5. Ability of O_2 and H_2 accumulator vent and relief assemblies to maintain the accumulator pressure below the maximum allowable	S			S		P	
6. Structural verification of LO_2 and LH_2 tanks and accumulators for burst pressure, cyclic pressure, and creep			P				
PROPELLANT GAUGING ASSEMBLY							
1. Capability of gaging assemblies to withstand boost environment	S			P			
2. Ability to determine propellant load within required limits					S	P	
HOT GAS VENT ASSEMBLY (PROPULSIVE, NONPROPULSIVE, GAS GENERATOR)							
1. Ability of vent to maintain proper back pressure on pump turbines, heat exchangers, etc.	S			S		P	
2. Capability of nonpropulsive vent to limit force output to required maximum	S			P		S	
ATTITUDE CONTROL THRUSTER ASSEMBLIES							
1. Ability to leak check engine/vehicle interfaces	S					P	
2. Capability to conduct engine functional sequence checks				P		S	
3. Ability to change attitude-control thrusters in horizontal or vertical attitude	S					P	

Table 5-4. Auxiliary Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
ORBIT MANEUVERING THRUST CHAMBER ASSEMBLIES							
1. Capability of thrust chamber assembly to be gimbaled at the required angles, rates, and responses	S			S		P	
2. Ability to align thrust chamber vector to vehicle center of gravity	S						P
3. Ability to leak check engine/vehicle interfaces	S					P	
4. Capability to conduct engine functional sequence check					S	P	
5. Capability to change orbit maneuvering engine in horizontal attitude	S				S	P	
APS/GSE							
1. Compatibility of subsystem/vehicle/SE interfaces						P	S
2. Ability to inert engine, tanks, lines, etc.	S					P	S
3. Capability to precondition LH_2 sections prior to propellant loading	S					P	S
APS/IAS							
1. Compatibility of auxiliary propulsion subsystem with various elements of the integrated avionics subsystem (IAS)					S	P	
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Vehicle electrical signal returns single-point ground is maintained after harness installation							P
2. No excessive leakage current exists through the harness insulation							P

Table 5-4. Auxiliary Propulsion Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
3. Harness insulation integrity after installation							P
4. Electromagnetic compatibility at the subsystem level							P
5. Internal cleanliness of tube systems is maintained in accordance with specification				P			
6. Tube systems structural integrity							
7. External leakage through mechanical, brazed, or welded tube joints not to exceed specification							P
8. Specified operation of each designated cluster of thrusters					S		P
9. Specified operation of the propellant management subsystem					S		P
10. Specified operation of the pressurization subsystem					S		P

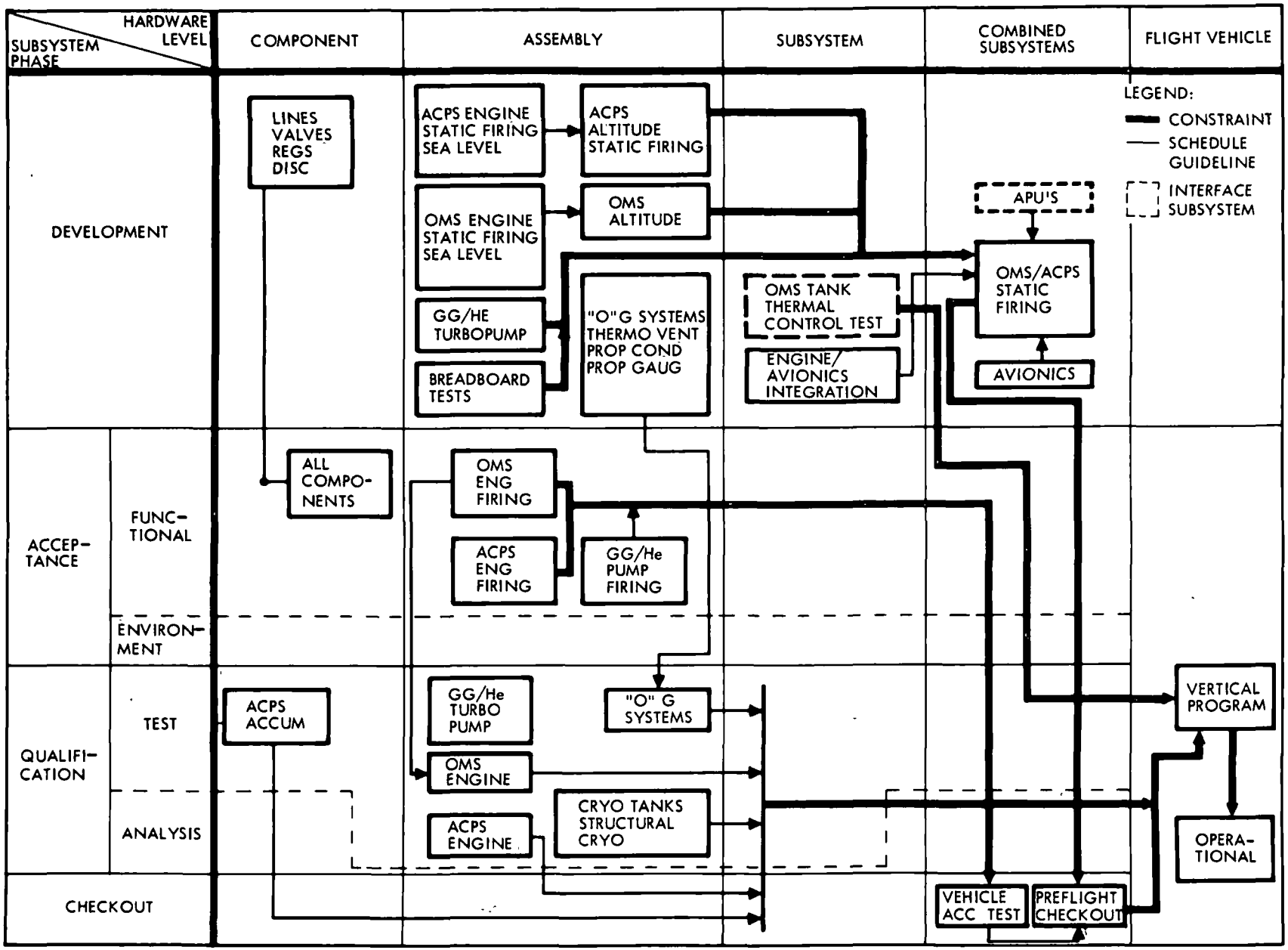


Figure 5-7. APS Test Logic and Constraint Network

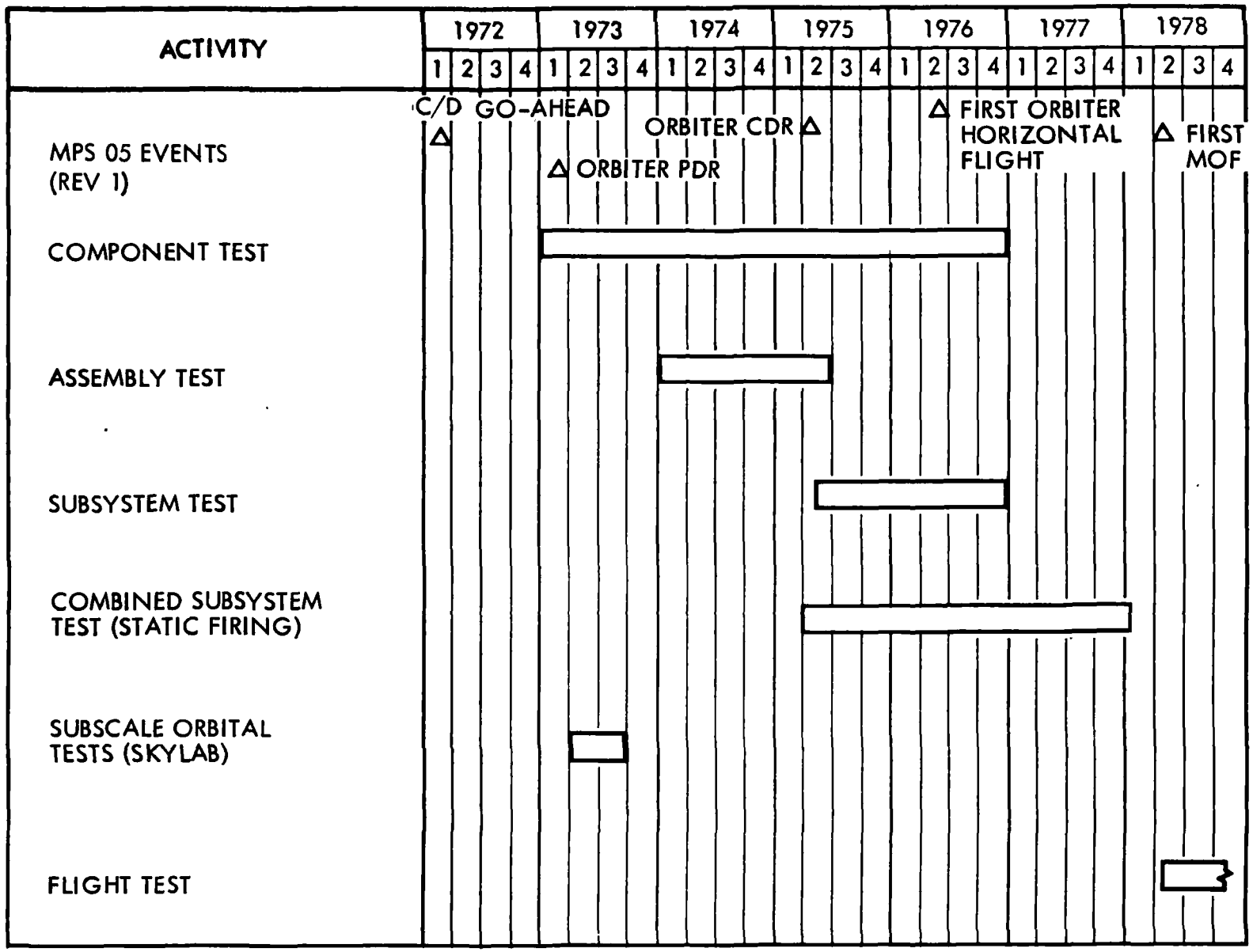


Figure 5-8. Preliminary APS Test Schedule

Table 5-5. APS Assembly Test Hardware Requirements

Assembly	Develop Breadboard Assembly Response/ Performance	Quantity (percent)		Subsystem*** Compatibility
		OMS Engine Interface Compatibility	Thruster Interface Compatibility	
Propellant feed and gaging(1)	50	100	-	100**
Turbopump(2)	100	100	-	100**
Pressurization	-	-	-	100**
Accum/feed	-	-	100	100
Thrusters(3)	-	-	10*	10*
Subscale tank assy(4)	-	-	-	100
Tank set and vents(5)	-	-	-	400**

*Use thruster interface compatibility thrusters

**Reuse for combined subsystem test

***The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.

(1) One set LO_2 lines to OMS supplier and 50 percent gaging system.
(2) Six turbopump packages to OMS engine supplier for test; reused on combined subsystem testing.
(3) Four thrusters and one manifold required for subassembly test; reused on combined subsystem testing.
(4) Special design tank assy for zero-g testing.
(5) One LH_2 downstream tank, 3 ACPS thrusters, and 1 set LH_2 lines.

Table 5-6. APS Test Support Requirements

Item	Requirement
Facility	
	Electrical power - 60 cycles, three phase - 120v, 440v; 28 vdc
	Water-firex, potable
	LO_2 storage/transfer
	LH_2 storage/transfer
	GO_2 storage/transfer
	GH_2 storage/transfer
	LH_2 storage/transfer
	He storage/transfer
	H_2 disposal
	Structure to support cold flow tests
	Test control room
Support equipment	
	OMS engine inertia simulator
	Test gas distribution/regulation
	Test control console
	Data acquisition
	Flow measuring apparatue
	Propellant distribution and pressurants
	Miscellaneous environmental test equipment
	Hydraulic and electrical load banks
Software	
	Control of test sequence

Note: The requirements identified are for testing of selected assemblies, *and do not reflect requirements for all APS assemblies* or for development/qualification of components or subassemblies.

5.3 AIR-BREATHING ENGINE SUBSYSTEM (ABES)

5.3.1 Description

The orbiter air-breathing engine subsystem provides the capability for powered descent after entry, powered landing approach and go-around, and ferry flight to selected launch sites.

The baseline ABES for the orbiter system incorporates four turbo-fan engines mounted in individual deployable nacelles that are stowed within the upper fuselage adjacent to the cargo hold. An additional fixed mounted ABE and additional fuel tankage is provided to satisfy the requirement for self-ferry capability. The baseline system incorporates removable auxiliary tanks located in the cargo bay and interfacing with the vehicle fuel, fuel-feed, and venting system. The engine fuel feed is pump augmented and utilizes a vented tank. Four nacelle-mounted engine-driven gearboxes, generators, and hydraulic pumps are provided for ferry flights to supply the vehicle with hydraulic and electrical power.

A block diagram of ABES hardware is given in Figure 5-9 and the sub-assembly schematic is shown in Figure 5-10.

5.3.2 Requirements

The ABES test requirements are delineated in Table 5-7 and are categorized by method of verification.

5.3.3 Approach and Rationale

To support component development and related subsequent requirements of the air-breathing engine subsystem, material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the ABES. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seals, lubricant, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Compatibility of materials in contact with each other in environments which may result in degradation of properties.

4. Effects of structural and fluid system corrosion on useful life of critical materials.

5. Physical and mechanical properties of shuttle materials which have not been previously established.

6. Joining methods for candidate alloys for shuttle structural and thermal requirements.

7. Development of materials accelerated life-test methods.

8. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, and assembly level. Subsystem and combined subsystem level ground thermal-vaccum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6. 6.

In general, ABES components and assemblies will be supplier developed or qualified as a normal part of the procurement cycle. Cost and schedule effectiveness may be realized in the ABE development or qualification as an uprated version of a previously developed military power plant is planned for common use on orbiter and booster.

Initial test effort will be directed toward the determination or demonstration of engine inlet duct performance utilizing subscale models in the subsonic wind tunnel program.

Prototype inlet ducts and partial nacelle structure will be provided to the ABE supplier for use in the engine static and altitude wind tunnel test program.

Concurrent with the engine manufactur's development and qualification program, an ABES static firing test stand will be activated for overall subsystem testing. This phase of testing will progress from various assembly levels through subsystem testing. Initial testing will integrate the fuel feed assembly, including ferry kit requirements in order to evaluate their effects on the engine under varying fuel flow conditions, power levels, and attitude. During later phases of this test program, engine instrumentation, controls and COFI, and miscellaneous engine accessories (starters, heaters, insulation, fire detection, and extinguishing, etc.) will be added to obtain more complete subsystem test data. The auxiliary power generation remote gearbox installation will also be evaluated during this phase of testing. Engine

deployment tests under simulated loading conditions will be performed on a separate test fixture.

The horizontal flight test program on Orbiter 1 will provide inflight performance data of the overall ABES and interfacing subsystems. Final subsystem demonstration will occur during the orbital test program where zero-g and vacuum effects data may be obtained.

The test logic and constraint network is shown in Figure 5-11. The preliminary ABES development schedule is given in Figure 5-12.

5.3.4 Test Article Requirements

Hardware required for ABES subsystem-level tests is listed in Table 5-8.

5.3.5 Support Requirements

Subsystem level support requirements are listed in Table 5-9.

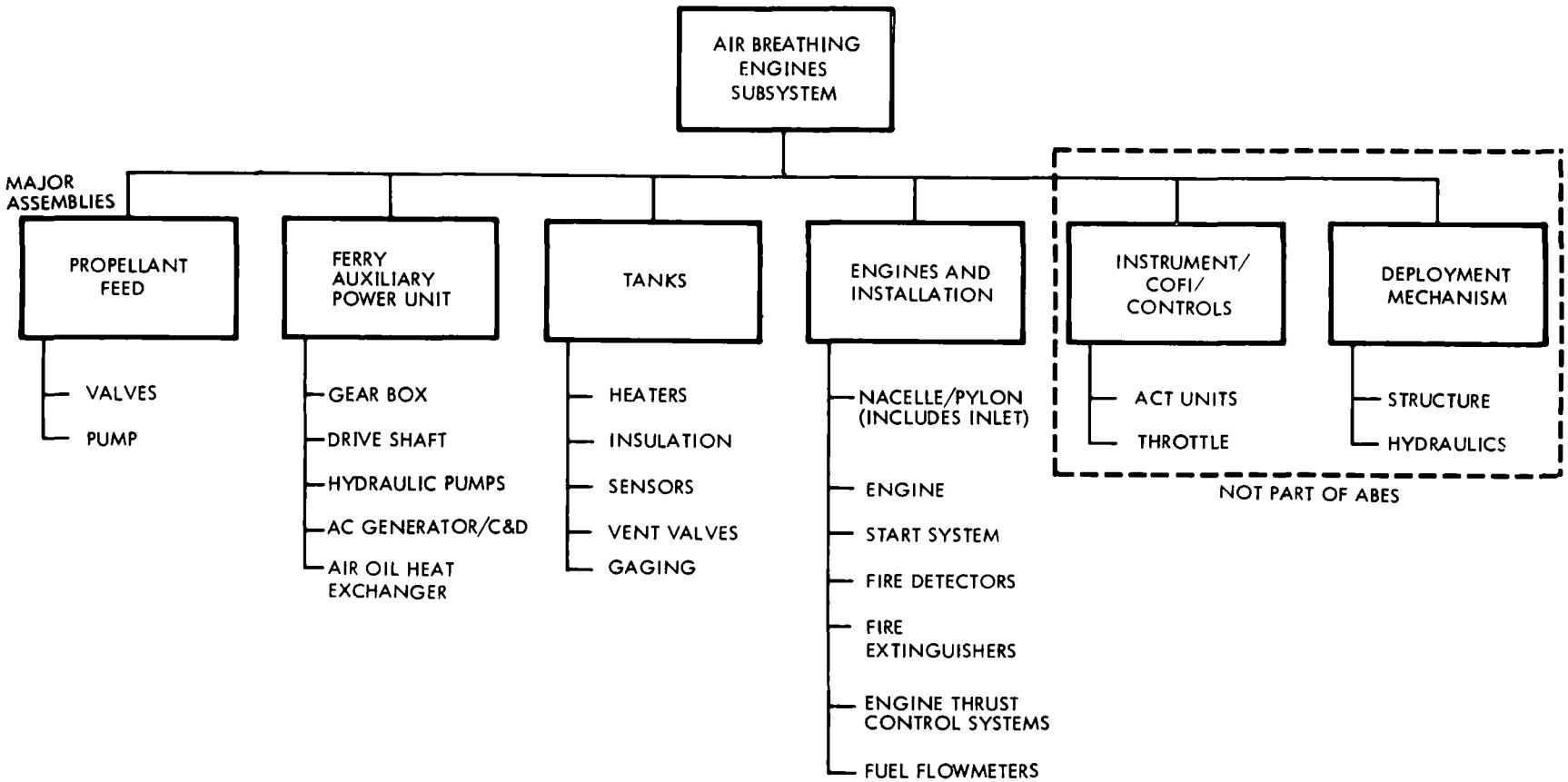
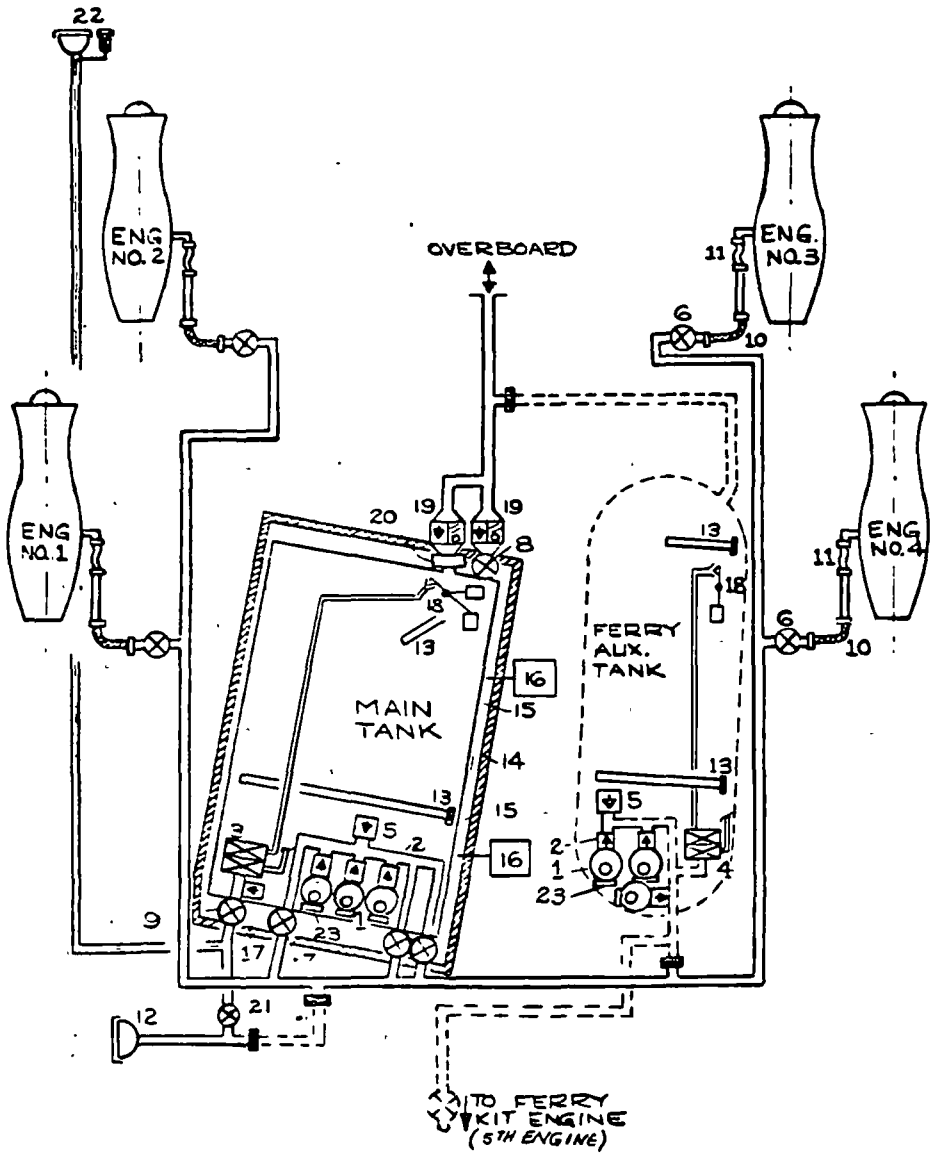


Figure 5-9. Air-Breathing Engine Subsystem Elements



1. BOOSTER PUMP (PLUG-IN TYPE)
2. BOOSTER PUMP CHECK VALVE
3. LEVEL CONTROL VALVE-MAIN TANK
4. LEVEL CONTROL VALVE-AUX. TANK (N.C.)
5. SUCTION FEED CHECK VALVE
6. ENGINE ISOLATION VALVE
7. TANK ISOLATION VALVE-FEED SYSTEM
8. TANK ISOLATION VALVE-VENT SYSTEM
9. TANK ISOLATION VALVE-FILL & DRAIN
10. ENGINE DEPLOYMENT COUPLING HOSE
11. ENGINE CONNECTOR HOSE
12. FILL & DRAIN ADAPTER & CAP (GROUND)
13. FUEL GAGING PROBE
14. BLANKET INSULATION
15. BLANKET HEATER
16. HEATER CONTROL UNIT
17. DRAIN CHECK VALVE
18. LEVEL CONTROL VALVE SENSOR
19. VENT VALVE
20. TANK VENT BURST DISC
21. HORIZONTAL SERVICING ISO VALVE
22. FILL & DRAIN ADAPTER & CAP (VERTICAL MODE)
23. PUMP REMOVAL CHECK VALVE

Figure 5-10. ABES Fuel System Schematic

Table 5-7. Air-Breathing Engine Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL							
1. Capability to accelerate engine thrust from idle descent to maximum power				P	S		S
2. Ability of installed engine to provide thrust required for go-around	S			P			S
3. Ability of installed engine to provide required thrust for takeoff				P			S
4. Ability of installed engines to provide SFC required for ferry	S			P			S
5. Capability of fuel supply, thrust control, engine and air-starter assembly to provide required air-start envelope	S			P			S
6. Capability to air-start engines without starter within wind milling envelope				P			S
7. Accessibility of ABE subsystem components					S		P
8. Capability of removing and reinstalling entire ABES to satisfy alternate mission requirements	S						P
9. Ability to install and remove ferry kit	S						P
10. Capability of subsystem to operate after exposure to orbital environment	S		P				S
11. Capability to change the normal engine lubrication system from the space storage isolated lube tank				P	S		S
ENGINE INSTALLATION							
1. Capability to purge lubrication system prelaunch			S		P		S
2. Ability of engine mounts and thrust bearings to withstand boost loads	S		P				S
3. Compatibility of engine front face with vehicle induced velocity and pressure distribution				P			S

Table 5-7. Air-Breathing Engine Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	1 Analysis	2 Computer/Model	3 Component	4 Assembly	5 Subsystem	6 Comb. Subsystem	7 Flight Vehicle
4. Capability of ground start unit to provide engine with specific pneumatic flow and pressure					P		S
5. Capability to deploy engines in specified flight envelope and flight loads				P			S
6. Capability of nacelle cooling and ventilation to maintain nacelle structure and engine temperatures within specified limits				P			S
7. Capability of engines to provide specified thrust and SFC within the flight envelope and ground-operating conditions				P			S
8. Ability of engine to provide required steady-state performance and transient response over the flight envelope	S			P			S
9. Engine can be replaced under specified conditions	S						P
FUEL SYSTEM							
1. Capability to fuel the vehicle in horizontal and vertical attitudes					P		S
2. Capability of ferry kit to provide fuel to the engine at specified conditions						P	S
3. Ability of fuel system to provide fuel to the engine at specific conditions				S	P		S
4. Ability of fuel tank vent and relief assemblies to maintain tank pressures during all operational modes						P	S
5. Capability of quantity gauging system to indicate fuel quantity with specified limits					P		S
6. Ability to defuel the vehicle in the horizontal or vertical attitude	S				P		S

Table 5-7. Air-Breathing Engine Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
MISCELLANEOUS							
1. Ability to service lube system				S	P		S
2. Capability to maintain throttle lever-to-engine control shift within specified limits					P		S
3. Ability of one fire extinguishing system to inert one engine pod				S	P		
4. Engine/vehicle/SE interfaces					S		P
5. Engine/COFI interfaces				S	S	S	P
6. Ability of thrust control to maintain control of engine power level					P		S
7. Compatibility of fuel and engine heater requirements with the EPDS	P		S				
8. Capability of fire detection assembly to sense and indicate only valid overheat conditions				S	P		
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Vehicle electrical signal returns single point ground is maintained after harness installation							P
2. No excessive leakage current exists through the harness insulation							P
3. Harness insulation integrity after installation							P
4. External leakage through mechanical, brazed, or welded tube joints must not exceed specification							P

Table 5-7. Air-Breathing Engine Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
5. Verification of operation of motor operated fuel tank isolation valves, engine isolation valves, refueling isolation valve, and vent isolation valve.							P
6. No leakage through isolation valves							P
7. Proper operation fuel tank heaters and level sensors							P
8. Structural verification of main tank and ferry tank for maximum burst pressure, cyclic pressure, and creep			P				

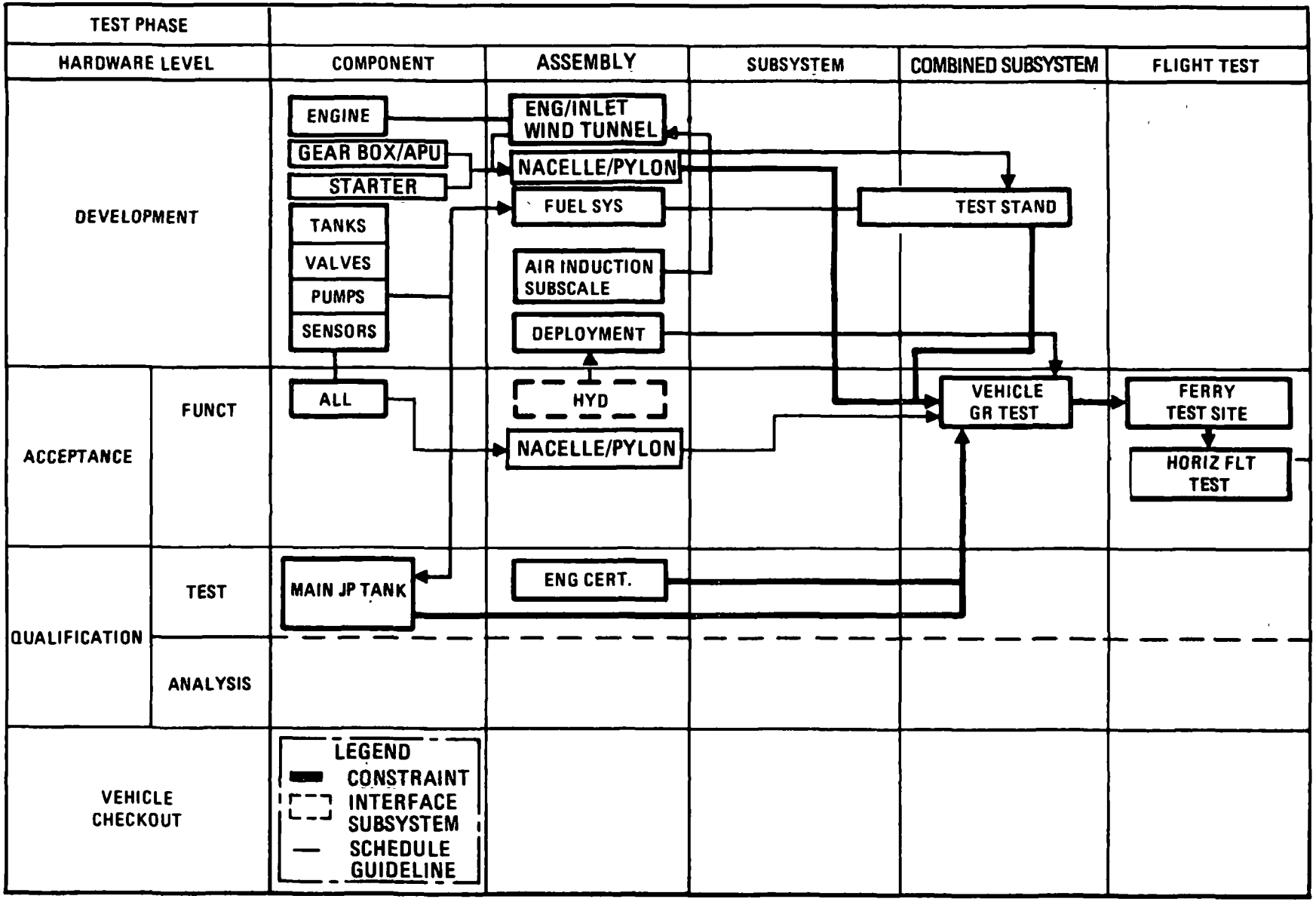


Figure 5-11. ABES Test Logic and Constraint Network

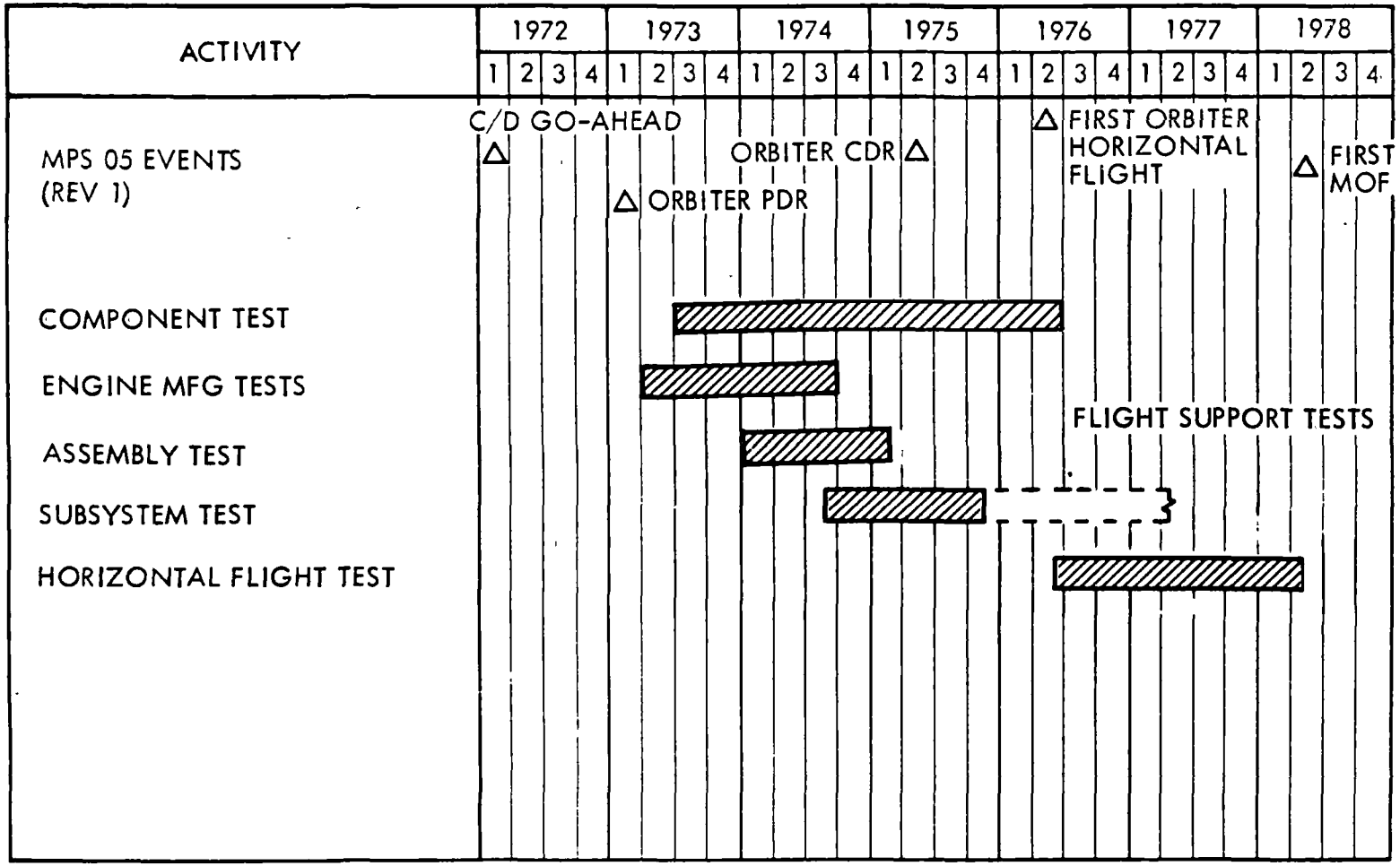


Figure 5-12. ABES Test Schedule

Table 5-8. ABES Test Hardware Requirements

Assembly	Quantity		
	ABES Static Firing	Deployment Fixture	Structural Verification
Engines and installation	2		
Propellant feed	1		
Propellant tank set			3
• Ferry tank			3
• Main tank	1		
Deployment hardware		1	
Ferry kit hardware	20%		

Note: The hardware quantities identified are for subsystem level testing and do not include requirements for development/qualification of individual components and subassemblies.

Table 5-9. ABES Test Support Requirements

Item	Requirement
Facility	Electrical power - 60 Hz 3 phase, 120 volts, 440 volts; 28 volts d.c. Water - Firex, potable JP4 storage/transfer GN_2 storage/transfer Structure to support test article during static firing Test control room
Support equipment	Test gas distribution/regulation Test control console Control/simulation/data acquisition computing capability Sound barrier Pneumatic ground start cart Thrust measuring system Lube servicing unit Hydraulic servicing unit Hydraulic power unit Electric load bank Hydraulic load bank

Table 5-9. ABES Test Support Requirements (Cont)

Item	Requirements
Software	Programs to implement following: Control of test sequence Simulation of DCM Data acquisition Test reporting CRT display of test data Data analysis

Note: The requirements identified are for subsystem level testing, and do not include requirements for development/qualification of individual components and subassemblies.

5.4 ELECTRICAL AND MECHANICAL POWER GENERATION (EMPG) SUBSYSTEM

5.4.1 Description

The power generation subsystem provides electrical and mechanical power for orbital and ferry missions. During orbital missions, the fuel cells are the prime source of electrical power and potable water for life support. Auxiliary power unit (APU) driven generators provide additional electrical power during boost, entry, and landing. Hydraulic power pumps are also APU driven. During ferry missions, electric and hydraulic power is derived from the ABES engines. The ferry flight kits include hydraulic pumps and ac generators. Batteries provide emergency power for restart of APU's or fuel cells in the event of loss of all primary power. Reactants for the fuel cells and O_2 for the ECLSS are stored and distributed by the power reactant supply and distribution assembly (PRSD). Heat for expulsion of supercritical reactants from the PRSD is provided electrically. Propulsion grade reactants for the APU's are supplied from the APS accumulators (Section 5.2).

Organization of power generation subsystem hardware is shown in Figure 5-13. A schematic is given in Figure 5-14.

5.4.2 Requirements

Verification requirements for the power generation subsystem are given on Table 5-10.

5.4.3 Approach and Rationale

Figure 5-15 shows overall test logic and constraints for the power generation subsystem. The PRSD, fuel cells, and APU's are major assemblies which will be developed separately and later brought together for various levels of testing. Each will be developed by a separate subcontractor. Issues designated for component or assembly level testing on Table 5-10 will be certified by the subcontractors. This includes such items as verification of flow dynamics under cryogenic conditions and demonstration of reactant expulsion rates. PRSD, fuel cell and APU development and certification for operation will include mission environmental conditions of temperature, pressure, shock, acceleration, acoustics, and vacuum.

To support component development and related subsequent requirements of the power generation subsystem, material and process testing will

be performed to evaluate, characterize, select, and substantiate the selection of materials. Areas to be investigated include the following:

1. The ability of seals, lubricant, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3 Performance of thermal control coatings under long duration earth orbital exposure.

4. Compatibility of materials in contact with each other in environments which may result in degradation of properties.

5. Effects of structural and fluid system corrosion on useful life of critical materials

6. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

The PRSD and simulated fuel cells will be integrated by the PRSD subcontractor. Actual fuel cells and the PRSD will be integrated during ground test of a flight vehicle. Presently available data and experience with a similar PRSD-fuel cell arrangement eliminates the need for extensive integrated test of these assemblies prior to the flight vehicle.

APU's will be integrated with the APS reactant supply system during the APS static firing program described in Section 6.4. Issues to be verified during the latter program are designated for combined subsystem test on Table 5-10.

Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, or assembly level. Subsystem and combined subsystem level, ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6.

After a stable, operating power-generation subsystem has been developed, it will be integrated with other vehicle subsystems. This will be accomplished at the flight vehicle in two steps: initially, during dry integration test, and then, during ground testing of the same vehicle.

Final demonstration of the power generation subsystem will take place during the horizontal and vertical flight test programs. Although fuel cells are not the normal source of power during horizontal flight, they will be included in the horizontal test program of FTV No. 1, to provide an adequate confidence level. A preliminary schedule, showing milestones in power generation subsystem development, is given on Figure 5-16.

The in-process phase of power generation subsystem checkout will verify correct subsystem installation. Functional checkout will be limited to those operations necessary to ensure a safe and economical closeout of structural assemblies, i.e., the forward, intermediate, and aft fuselages.

After the orbiter modules are connected and final interfaces are tested, the entire subsystem will be tested. The checkout will be followed by an integrated test of all systems.

5.4.4 Test Article Requirements

Power generation subsystem level test article requirements are summarized in Table 5-11.

5.4.5 Support Requirements

The APS static firing facility described in Section 6.4 is the major integrating contractor level article for development testing of the power generation subsystem. Since development testing of the APU's, PRSD, and fuel cells will be accomplished by subcontractors, those facilities are not described in this plan.

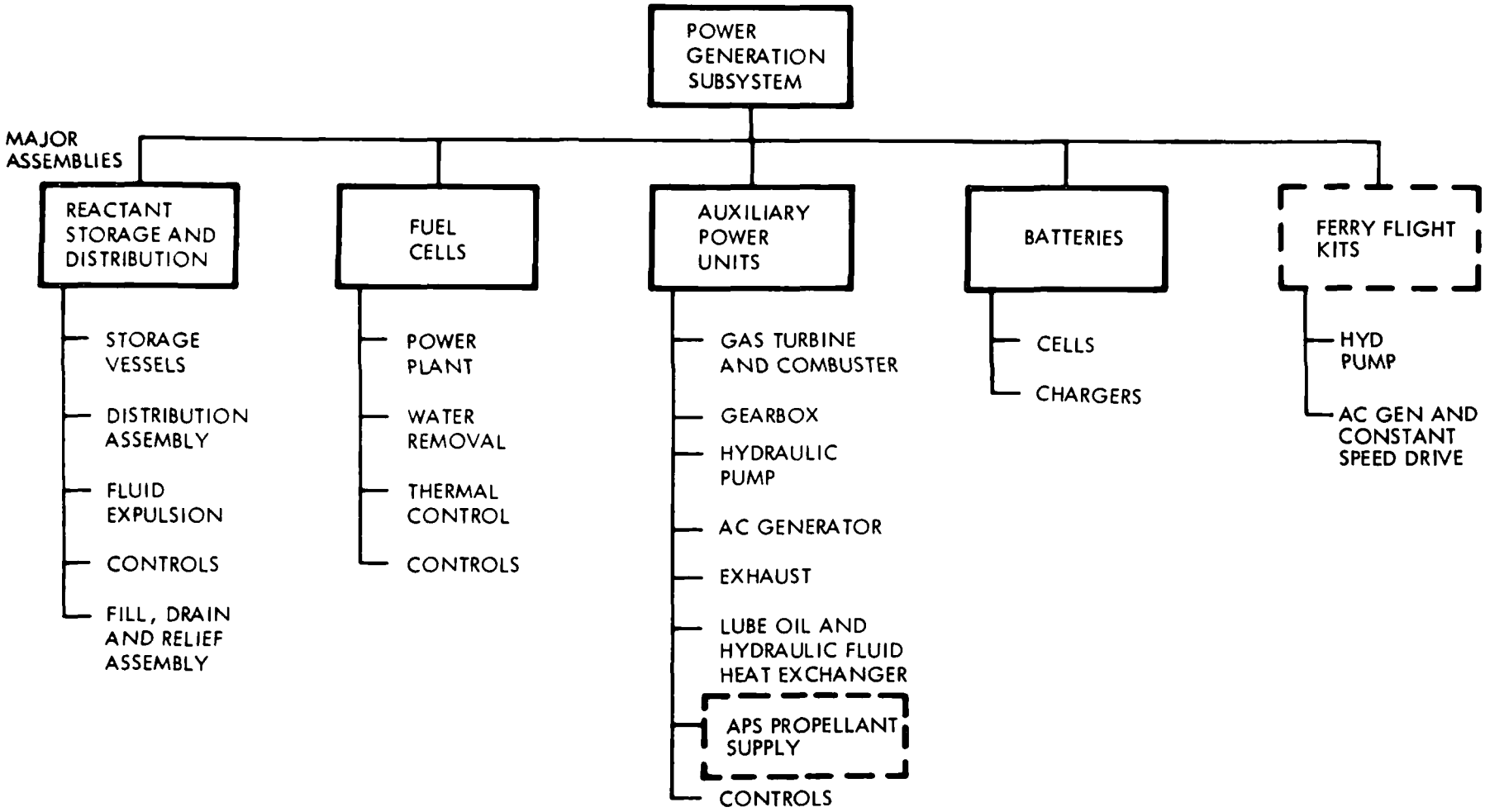
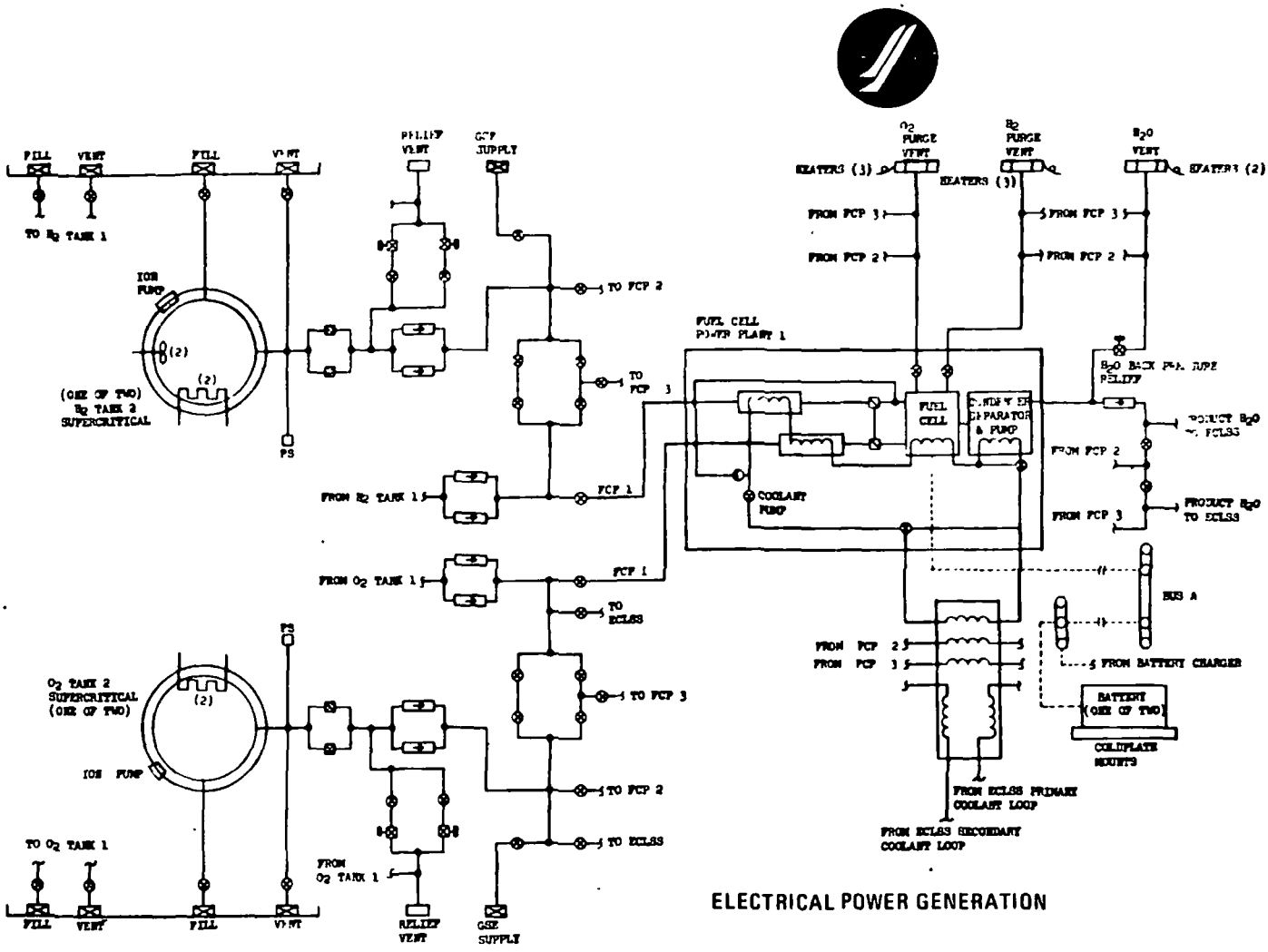
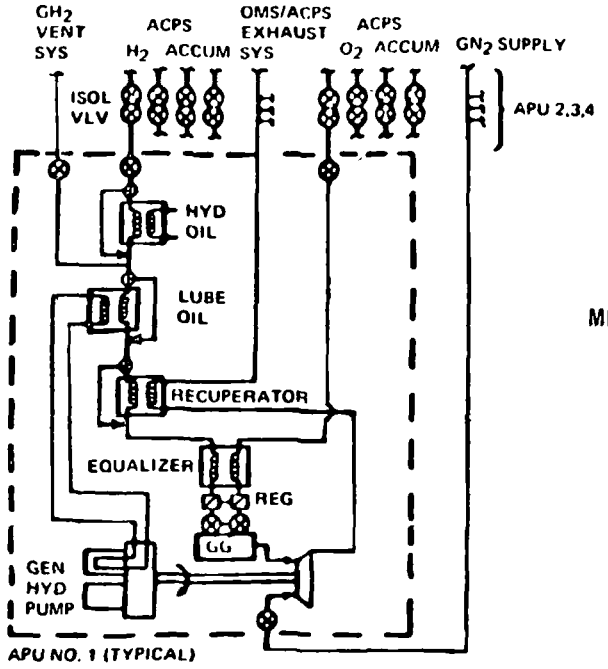


Figure 5-13. Power Generation Subsystem Elements



ELECTRICAL POWER GENERATION



MECHANICAL POWER GENERATION

Figure 5-14. Electrical/Mechanical Power Generation Subsystem

Table 5-10. Power Generation Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL							
1. All subsystem components are accessible for maintenance.	S			S			P
2. Replaceable system fillers, reactant purifiers, and other periodically replaceable components are readily accessible and can be replaced in horizontal or mated vertical position.	S			S			P
3. All fluid, electrical, and pneumatic connectors are accessible, that they can be readily mated and disconnected, and that positive means of preventing cross connections provided.	S			S			P
4. Subsystem can be monitored and controlled by crew from cockpit or from ground using support equipment.							P
5. Subsystem can be managed by DCM.							P
6. Compatibility of components with reactants.	S		P	S			
7. Ability to perform leak checks.			S	P			S
8. Structural margins of all pressure vessels and critical components allowed.	S		P				
9. Installation tolerance to all handling and flight loads, allowed.				P			S
10. Check for proper thermal control of all sensitive components.	S			S		P	
11. Subsystem can withstand mission environmental conditions of temperature, pressure, vibration, shock, acceleration, acoustics, vacuum, and zero-g.			S	P			S
12. Functional interface exists between power subsystem and other vehicle subsystems.				S		S	P
13. Capability for functional checkout of redundant elements.	S						P
14. PRSD has sufficient capacity for mission duration, including pre-launch and post-landing activities.		P					S

Table 5-10. Power Generation Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL (Cont)							
15. PSRD has sufficient capacity for emergency mission contingency under critical failure conditions.		P					S
16. Overall subsystem is stable under specified operating conditions.	S			S		S	P
17. PRSD can supply fuel cells with reactants and ECLSS with oxygen.	S			P			S
18. PRSD controls maintain desired reactant pressure and flow rates under specified conditions.		S		P			S
19. Fuel cells and ECLSS can be operated while vehicle is on the ground, using ground source for reactants.					S		P
20. Ability of electrical heaters to transfer heat energy to the PRSD vessels for desired reactant expulsion rates under normal and emergency conditions.		S		P			S
21. PRSD reactants are supplied at the fuel cell interface at the defined conditions of mass flow, pressure, and temperature.	S		S	P			
22. Life cycle limits of materials, components, and assemblies are within specified limits.	S		S	P			
23. Materials exposed to oxygen normally or after a single or double failure do not constitute a safety hazard.	S		P				
FUEL CELLS							
1. Fuel cells can be started or shut down within specified period while on ground or in flight and exhibit specified capabilities at the end of the start sequence.				P			S
2. Fuel cell product water quality and quantity are within specified limits.				P			S

Table 5-10. Power Generation Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
FUEL CELLS (Cont)							
3. Ability of fuel cells to separate and discharge water during all ground, launch, and reentry phases imposing high back pressure on the water discharge system.	S			P			S
4. Fuel cell and product water lines are provided an environment adequate to preclude water freezing.	S						P
5. Fuel cell coolant loop can reject specified heat quantities to the ECLSS.	S			P			S
6. Fuel cell coolant loops can be filled, drained, and preserved for non-fluid storage in accordance with established procedures and equipment within specified time limits.				S			P
7. Fuel cell coolant loop fill can be checked for degree of entrained gas and particulate contamination.				P			S
8. All fuel cell coolant loop surfaces in contact with coolant are compatible with the designated coolant, storage conditions, and deterioration criteria.	S		S	P			
9. That fuel cell coolant contamination levels and coolant properties remain within acceptable limits for a specified time and cycle limit.				P			
10. Fuel cells can be purged in both manual and automatic modes under atmospheric and space vacuum conditions and under all vehicle orientation.				P			S
11. Fuel cells can provide normal electrical power demand after loss of one fuel cell for all mission modes.	S			P			S
12. Fuel cells can provide power-down, emergency-power demand after loss of two fuel cells for all defined emergency modes.	S			P			S
13. Fuel cells respond to transient load demands as specified under anticipated environments and at extremes of interface conditions	S			P			S

Table 5-10. Power Generation Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
AUXILIARY POWER UNIT (APU)							
1. APU's can be started or shut down within specified period on the ground and in flight.				P		S	S
2. APU's provide sufficient shaft horsepower to support system loads.	S			P			
3. APU's meet all operating requirements at sea level and operating altitude conditions.				P		S	
4. APU surface temperatures remain within specified limits.	S			P			S
5. Ability of APU mounts to withstand starting and operating loads.				P		S	
6. APU controls maintain specified inlet reactant temperatures, combustor temperature, and turbine speed.				S		P	
7. Turbine wheel-burst containment capability.	S		P				
8. APU gearbox lube temperature is maintained within specified limits.				P		S	
9. Ac generator output remains within limits under normal and step-load change conditions.				P		S	
10. Ac generators provide sufficient power during boost, entry, approach, and landing mission phases.	P			S			
11. Check ac generator capability with generator control unit (GCU).			S	P			
12. Satisfactory performance of APU exhaust ducts and system compatibility with SE burn stacks.						P	S
13. Orientation of APU exhaust is such that flame does not cause any impingement damage on orbiter or booster or does not cause hazards to ground personnel or equipment.	S						P

Table 5-10. Power Generation Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
AUXILIARY POWER UNIT (APU) (Cont)							
14 Fire walls and isolation valving are capable of isolating fires in the APU compartments	P			S		S	
15 Overheat detection system is capable of detecting an overheat condition in the APU compartments	S			P			
16. Fire extinguishers are capable of extinguishing fires in the APU compartment	S			P			
CRYOGENIC TANKS (PRSD)							
1. PRSD tanks can be filled and pressurized to supercritical regime within specified time period and within a specified fluid quality	S			P			S
2 PRSD tanks can be depressurized, drained, and safed within a specified time period, both in orbiter horizontal and vertical attitudes.	S			P			S
3 PRSD tanks can be filled and drained remotely.							P
4 Vacuum integrity of PRSD tanks annalus remains within specified limits after extended periods of storage, flight usage, and flight or handling conditions imparting loads to the tanks.		S		P			S
5. Heat leak rate into PRSD tanks during all ground and flight modes shall remain within specified limits	S			S			P
6 Effects of stratification on PRSD tank gaging shall be within specified limits				S			P
7 Dynamic characteristics of the PRSD shall be demonstrated under cold flow conditions	S			P			S
8 Tank depletion is nominally equal, using automatic pressure controls				P			S

Table 5-10. Power Generation Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
BATTERIES							
1. Batteries provide sufficient power output for reset of subsystem in the event of complete primary power system failure.	P		S				S
2. Compatibility of bettery and charger.						P	S
IN PROCESS ACCEPTANCE REQUIREMENTS							
1. Cable assembly continuity and bus isolation resistances are within specified limits.							P
2. Harness insulation resistances are within specified limits.							P
3. Electromagnetic interference levels are within specified limits.							P
4. Tubing networks are cleaned and dried as specified, prior to component/assembly installation.							P
5. Tubing networks can withstand proof pressure checkout limits, prior to pressure regulator installation.							P
6. Final fluid component installation leakages are within specified limits.							P
7. Functional checkout limits for battery and fuel cell installation closeout are as specified.							P
8. Functional checkout limits for APU installation closeout are as specified.							P

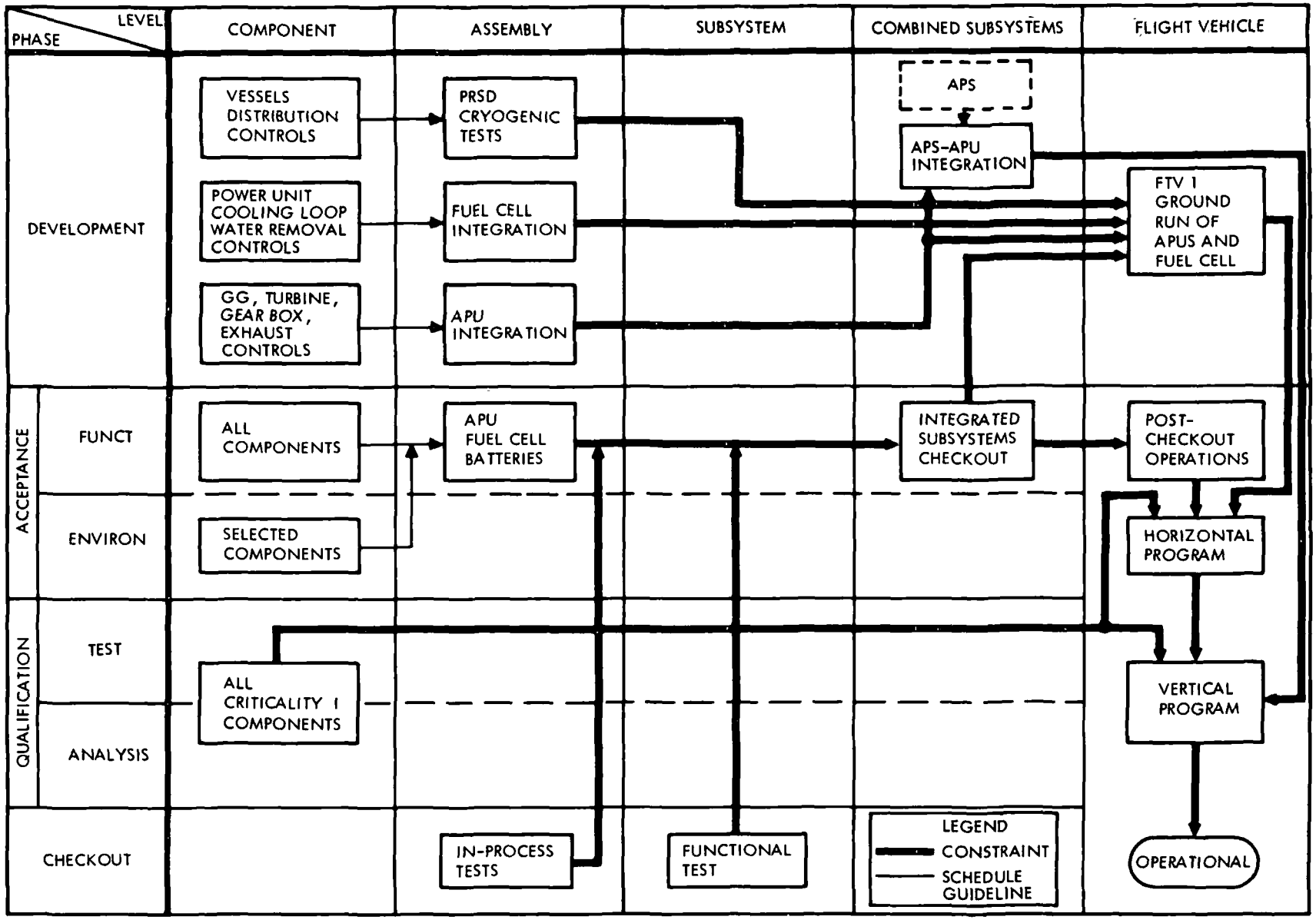


Figure 5-15. Electrical/Mechanical Power Generation Test Logic and Constraint Network

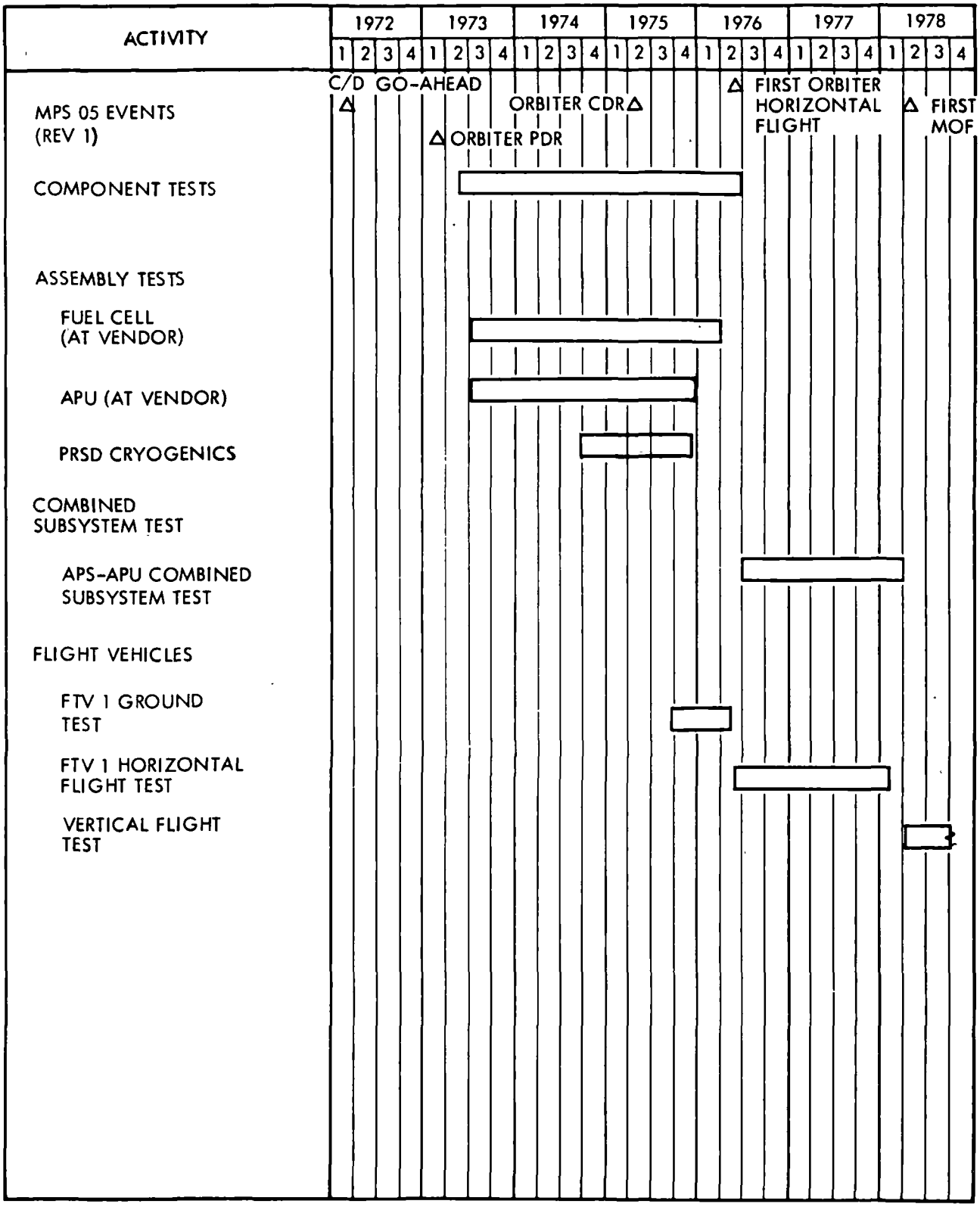


Figure 5-16. Electrical/Mechanical Power Generation Test Schedule

Table 5-11. Test Article Requirements for Electrical and Mechanical Power Generation Subsystem

Assembly	Quantity	
	Breadboard Tests	PRSD-Fuel Cell Integration
Battery	2	
Charger	1	
PRSD*		100%
Fuel cell (simulated)*		3

*These items are not included in the Table 3.1 hardware summary, as they are used by subcontractors rather than the orbiter contractor.

Note: The hardware quantities identified are for stated level tests, and do not include requirements for development or qualification or individual components and subassemblies.

5.5 HYDRAULIC POWER SUBSYSTEM

5.5.1 Description

The hydraulic power subsystem provides energy for actuation of aerodynamic surfaces, landing gear, brakes, steering, main and OMS engine gimbals, engine deployment, car cargo door deployment. Major elements of the subsystem are shown in Figure 5-17, and a schematic is given in Figure 5-18. The subsystem includes hardware for hydraulic power generation, distribution, control, and conversion to mechanical energy. Mechanical shaft power for the hydraulic pumps is provided by the APU's. High-pressure (4000 psi) fluid is distributed via lines to control valves and actuators, and then, returned to reservoirs. Conversion to mechanical output is accomplished by linear actuators and hydraulic motors.

The subsystem consists of four independent power assemblies. They provide mission capability after a single failure and in the event of a second failure, safe flight and landing.

5.5.2 Requirements

Certification requirements for the hydraulic power subsystem are given on Table 5-12. Special attention will be given to the following:

Dynamic stability of the integrated subsystem

Aerodynamic surface and rocket gimbal response

Interface with avionics

Servo actuator failure detection and isolation

Airbreathing engine deployment

To support component development of the hydraulic power subsystem, material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials. Areas to be investigated include the following:

1. The ability of seals, lubricant, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Performance of thermal control coatings under long duration earth orbital exposure.

4. Compatibility of materials in contact with each other in environments which may result in degradation of properties.

5. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

5.5.3 Approach and Rationale

Figure 5-19 shows the overall test logic and constraints for the hydraulic power subsystem. The distribution system and selected components, as well as integration of all hardware into an operating subsystem, will be developed by the orbiter contractor. Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, assembly level. Subsystem and combined subsystem level, ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6. Assembly-level tests will be incorporated into major test articles where subsystem interfacing is required. Main and OMS engine gimbal actuation hydraulic assemblies will be included in the respective cluster and static firing programs (Sections 6.1 and 6.4). The landing gear and brake hydraulic assemblies will be included in the landing subsystem test program (Section 5.17).

Initial integration of selected hydraulic power assemblies will take place at a hydraulics/controls laboratory. Subsystem assemblies to be installed and tested at the hydraulics/control laboratory are listed on Table 5-13 (the table also shows test locations of other hydraulic power assemblies). In order to adequately assess the dynamics of hydraulic power generation and distribution, in conjunction with hydraulic flight control components, a full scale layout of hydraulic lines is required, (i.e., actuators, servos, valves, accumulators, reservoirs, and controls). Actual physical layout of the lines will be duplicated to the extent feasible at the hydraulics/controls laboratory. Subsystem actuators will be cycled against simulated aerodynamic and inertial loads. The hydraulics/controls laboratory differs from the conventional Iron Bird in that all avionics gear is not present. Support equipment will ordinarily be used to produce the control commands required to operate the hydraulic subsystem. Later in the development test program, the hydraulics/controls laboratory will be connected electrically to the avionics systems integration laboratory (ASIL) for G/N&C end-to-end tests. This interconnection will exist only when end-to-end testing is desired; otherwise, the two test facilities will be operated independently. End-to-end tests are described in detail in Section 6.2, Avionics/Non-avionics Combined System Testing.

Final integration testing of the hydraulic system will occur at the vehicle level. Ground tests will demonstrate system adequacy for the succeeding flight test program. The horizontal and orbital flight test programs will be used to evaluate the hydraulic system components of the cargo door deployment system and ultimately to demonstrate the ability of the hydraulic system to meet mission requirements. Issues to be certified during independent operation of the hydraulics/controls laboratory are designated for subsystem, assembly, and, in some cases, component level testing on Table 5-12. Remaining component-level items will be certified by vendors or at the vehicle contractor's general test laboratories. Items slated for combined subsystem test on Table 5-12 will be certified during GN&C-hydraulic/controls end-to-end tests, propulsion subsystems, cluster, and static firings, and landing subsystem tests. Flight vehicle items will be certified during the flight test program. Successful completion of the integrated and hydraulics/control laboratory test programs will constitute flight certification with the final operational certification of the system to occur following completion of the horizontal and orbital flight test programs.

A preliminary test schedule is given in Figure 5-20. Test article requirements are summarized on Table 5-14.

The in-process checkout of the hydraulic power subsystem will include landing gear cycles to verify selector valve and actuator operation relative to flow rate and time interval in conjunction with verification of mechanical rigging relative to gear-and-door uplocks and downlocks. Nose wheel steering and brakes will also be verified for proper operation. ABES deployment will be verified relative to door open-and-close circuits, and speed and rotation of hydraulic motors. Cargo door actuation will be verified against proper functioning of shutoff valves and their relationships to the hydraulic circulation system. Control valve operation is verified through door locks and actuators with respect to rate and direction. Positions and rates of elevon and rudder/speed brake aerodynamic surfaces and engine gimbals will be verified against applied servo signals. Mechanical interfaces at the actuators will also be verified.

5.5.4 Test Article Requirements

Test article requirements are summarized in Table 5-14.

5.5.5 Support Requirements

Support capabilities required for the hydraulics/controls laboratory are summarized on Table 5-15.

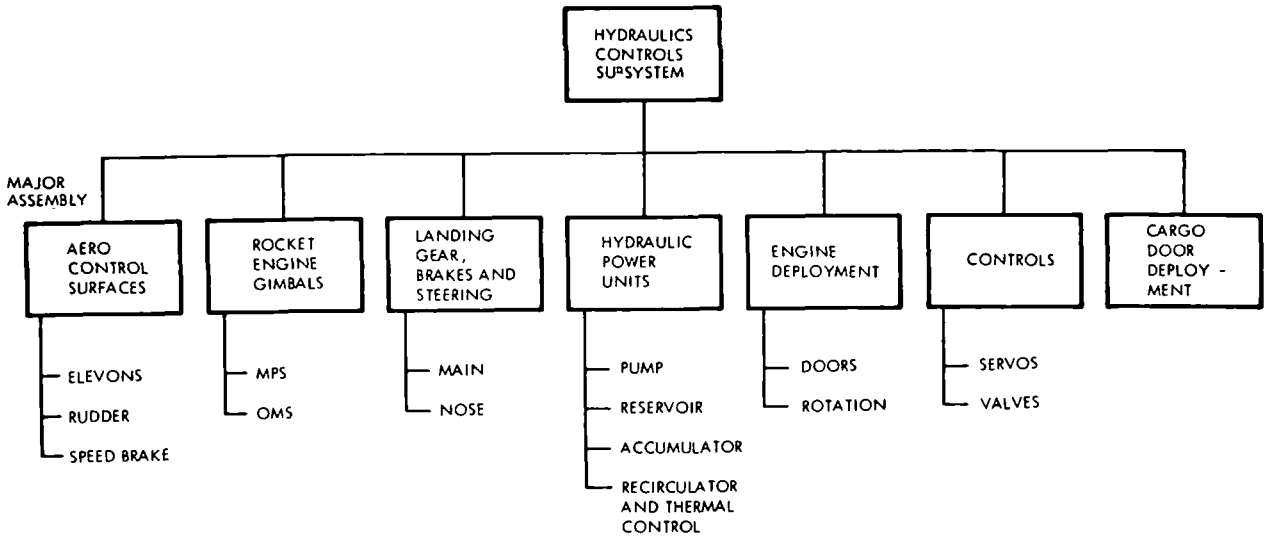


Figure 5-17. Hydraulic Power Subsystem Elements

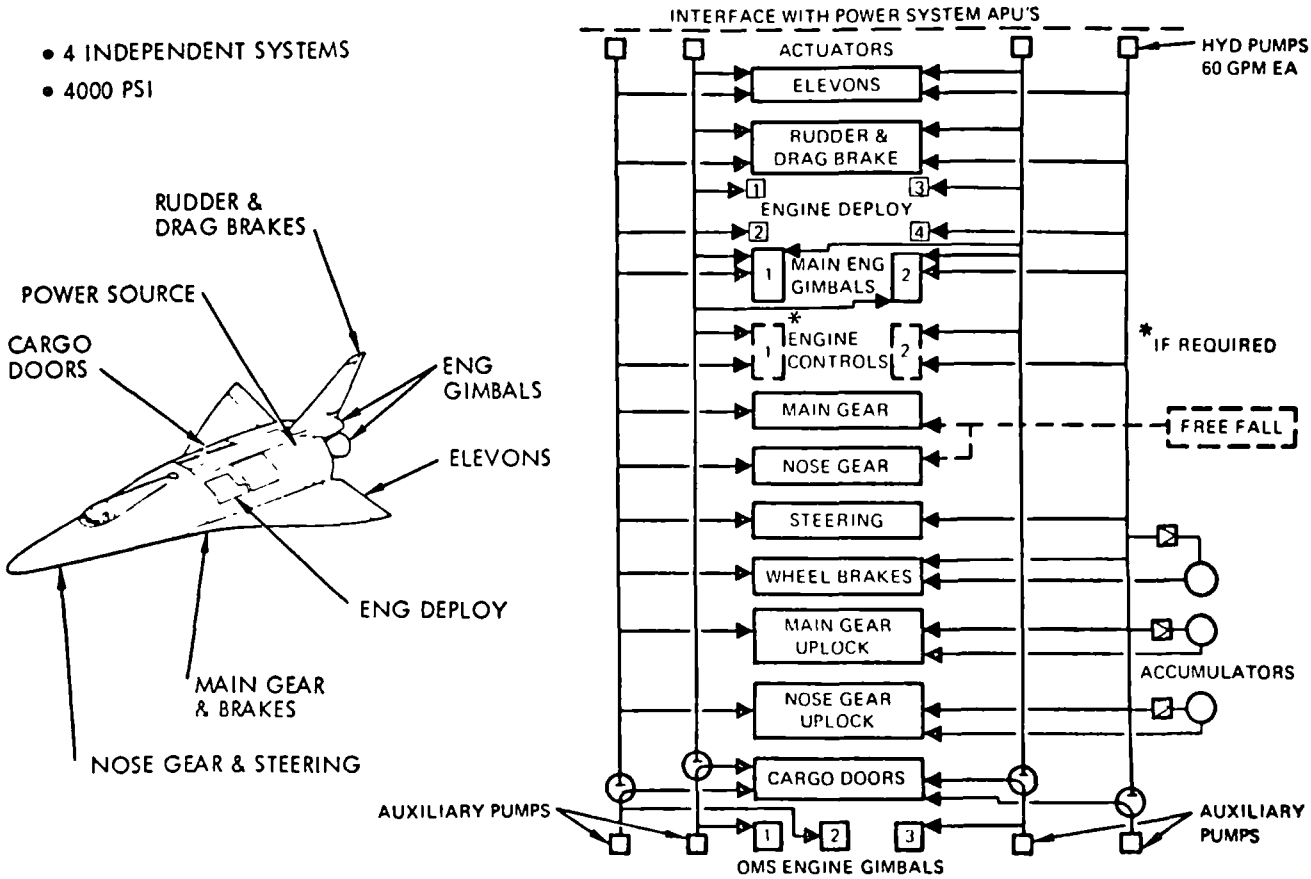


Figure 5-18. Hydraulic Power Subsystem Schematic

Table 5-12. Hydraulic Power Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
HYDRAULIC POWER DISTRIBUTION							
1. Ability to meet structural integrity requirements.							
Proof			P				
Gross system leak					S		P
Shock, acoustic and vibration			P				S
2. Subsystem servicing procedures, i.e., fluid, N_2, etc., are valid					P		S
3. Failure indication subsystem meets specified requirements.					P	S	S
4. Capability to meet maximum contamination level.					P		S
5. Capability at internal and external operational temperatures.							P
6. Component accessibility	S						P
7. Integrated pumping subsystem reliability.			P				
GENERAL							
1. Airborne system can be powered by a ground hydraulic power unit, for ground operations.					P		S
2. Selected subsystem components are accessible for servicing and maintenance.	S						P
3. Sufficient power is available to satisfy specified mission loads.	S				P		S
4. Techniques used for management of redundant subsystem elements are valid.	S				P	S	S
5. Functional interface between hydraulic power and other vehicle subsystems is verified.						S	P
6. Ability to thermally condition hydraulic fluid via the ECLSS heat exchanger.	S						P

Table 5-12. Hydraulic Power Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL (Cont)							
7. Ability to reject heat from the system via the hydrogen heat exchangers.	S						P
8. Subsystem ability to withstand mission and ground environment (temperature, pressure, shock, vibration, radiation, and weightlessness).	S		P	S			S
9. Ability to control and monitor subsystem from crew cabin.					S	P	S
LANDING GEAR, ENGINE DEPLOYMENT, CARGO DOOR							
1. Meet force capability (hinge moment) requirements.	S		P	S			S
2. Meet rate requirements.			P	S			S
3. Meet stroke (angular deflection) requirements.	S		P	S			S
4. Capability to withstand:							
Proof	S		P				
Burst	S		P				
Shock			P				S
Acoustic and vibration effects			P				S
5. Capability at specified internal and external temperature extremes.			P				S
6. Capability of meeting maximum internal leakage requirement.			P				
7. Sequencing capability (solenoid control valves).				P			S
8. To demonstrate satisfactory wear life and fatigue life in endurance tests.			P				
9. Meet integrated system reliability requirements.				P			

Table 5-12. Hydraulic Power Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
LANDING GEAR, ENGINE DEPLOYMENT, CARGO DOOR (Cont)							
10. Meet fail-operation and fail-safe capability requirements.				P			
11. External fluid leakage requirements are satisfied in a vacuum environment.			P				S
HYDRAULIC POWER GENERATION							
1. Capability to depressurize			P		S	S	S
2. Blocking capability			P				S
3. Operational capability at internal and external temperature extremes.			P				S
4. Variable delivery control.			P		S		
5. Speed of response.			P		S		
6. Pump stability.			P				
7. Capability to withstand acoustic and vibration effects.			P				
8. Rated delivery.	S		P		S		
9. Rated speed.			P		S		
10. Rated pressure.			P		S		
11. Ability to withstand proof pressure.	S		P				
12. Ability to withstand burst pressure.	S		P				
13. To demonstrate satisfactory wear life and fatigue life in endurance tests.			P				

Table 5-12. Hydraulic Power Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
HYDRAULIC POWER GENERATION (Cont)							
14. External fluid leakage requirements are satisfied in a vacuum environment.			P				
TVC SERVOACTUATORS							
1. Meet angular deflection requirements.	S		P		S	S	S
2. Meet rate requirements.			P		S	S	S
3. Meet gimbal load requirements.	S		P		S		S
4. Meet positioning accuracy requirements.			P		S	S	S
5. Meet dynamic response requirements.	S		P		S	S	
6. Meet internal fluid leakage requirements.			P				
7. Fault detection, isolation and FO/FS capability. (MPS actuators only)	S		P		S	S	S
8. Compatibility with avionics subsystems.						P	S
9. Accessibility of components	S						P
10. Meet proof pressure requirements.			P				
11. Meet burst pressure requirements.			P				
12. Meet acceleration, shock, vibration, and acoustic environment requirements.			P				S
13. Capability of operating within fluid temperature extremes.			P				S
14. Meet temperature environment requirements.			P				S
15. Meet static stiffness requirements.	S		P		S		

Table 5-12. Hydraulic Power Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	1 Analysis	2 Computer/Model	3 Component	4 Assembly	5 Subsystem	6 Comb. Subsystem	7 Flight Vehicle
TVC SERVOACTUATORS (Cont)							
16. Demonstrate satisfactory wear life and fatigue life.			P				
17. External fluid leakage requirements are satisfied in a vacuum environment.			P				
AEROSURFACES/SERVOACTUATORS							
1. Meet angular deflection requirements.	S		P		S	S	S
2. Meet rate requirements.			P		S	S	S
3. Meet hinge moment requirements.	S		P		S	S	S
4. Meet positioning accuracy requirements.			P		S	S	S
5. Meet dynamic response requirements.	S		P		S	S	
6. Meet internal fluid leakage requirements.			P				
7. Fault detection, isolation and FO/FS capability.	S		P		S	S	S
8. Compatibility with avionics subsystems.						P	S
9. Accessibility of components.	S						P
10. Meet proof pressure requirements.			P				
11. Meet burst pressure requirements.			P				
12. Meet acceleration, shock, vibration and acoustic environment requirements.			P				S
13. Capability of operating within fluid temperature extremes.			P				S
14. Meet temperature environment requirements.			P				S

Table 5-12. Hydraulic Power Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
AEROSURFACES/SERVOACTUATORS (Cont)							
15. Meet static stiffness requirements.	S		P		S		
16. Demonstrate satisfactory wear life and fatigue life.			P				
17. External fluid leakage requirements are satisfied in a vacuum environment.			P				
IN-PROCESS CHECKOUT							
1. The vehicle electrical signal, that returns single point ground, is maintained after harness and distribution box installation.							P
2. No excessive leakage current exists through the harness insulation.							P
3. Harness insulation integrity after installation.							P
4. Electromagnetic compatibility at the subsystem level.							P
5. Internal cleanliness of tube systems is maintained in accordance with specification.							P
6. Tube systems structural integrity.							P
7. Mechanical, brazed, or welded tube joints do not leak.							P
8. The landing gear downlock and uplock are rigged for proper gear operation.							P
9. The landing gear door actuators are rigged for proper door travel.							P
10. The nose wheel steering mechanism is rigged for proper operation.							

Table 5-12. Hydraulic Power Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
ABES Deployment							
1. The hydraulic control valves individually function properly with respect to a specified electrical input signal.							P
2. The engine compartment door actuators and power hinge actuators function properly with respect to control valve selections.							P
3. Rotation of hydraulic motor drive with respect to control valve selection.							P
4. No internal leakage exists within hydraulic control valves.							P
5. Proper electrical sequencing of control valves relative to door-open engine-deployment function.							P
Cargo Door Actuation							
1. Actuator control valves function properly with respect to a specified electrical input signal.							P
2. Proper electrical sequencing of recirculation shut-off valves and control valves with respect to one another.							P
Aerodynamic Surfaces - Elevons and Rudder/Drag Brake							
1. Determine through functional operation that actuator linkage adjustments are within specified limits and that mechanical clearance requirements are satisfied.							P
2. Verify correct polarity.							P
TVC Actuators							
1. Verify that minimum mechanical clearance requirements are satisfied.							P
2. Verify correct polarity (actuators detached from engines).							P

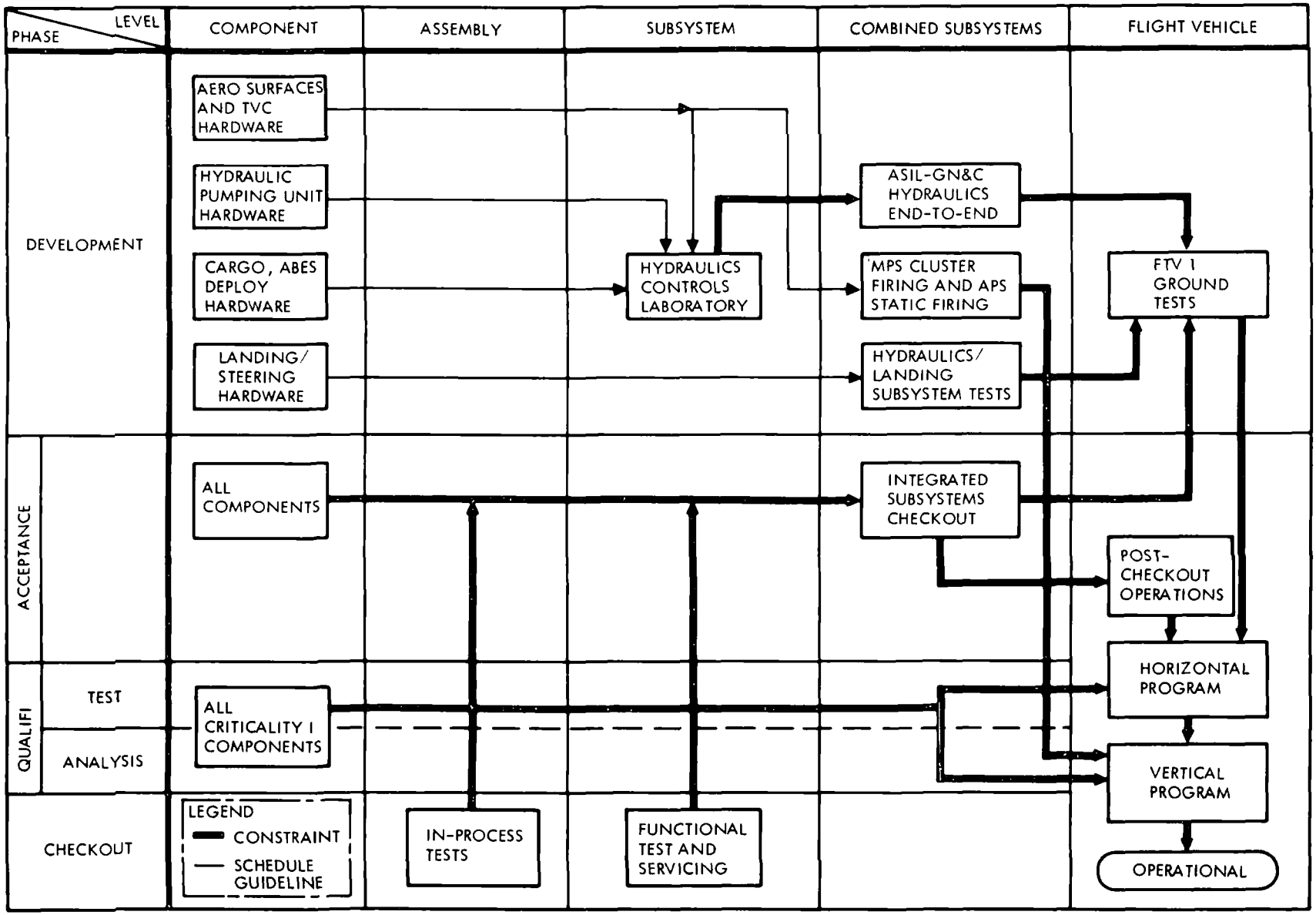


Figure 5-19. Hydraulic Power Subsystem Test Logic and Constraint Network

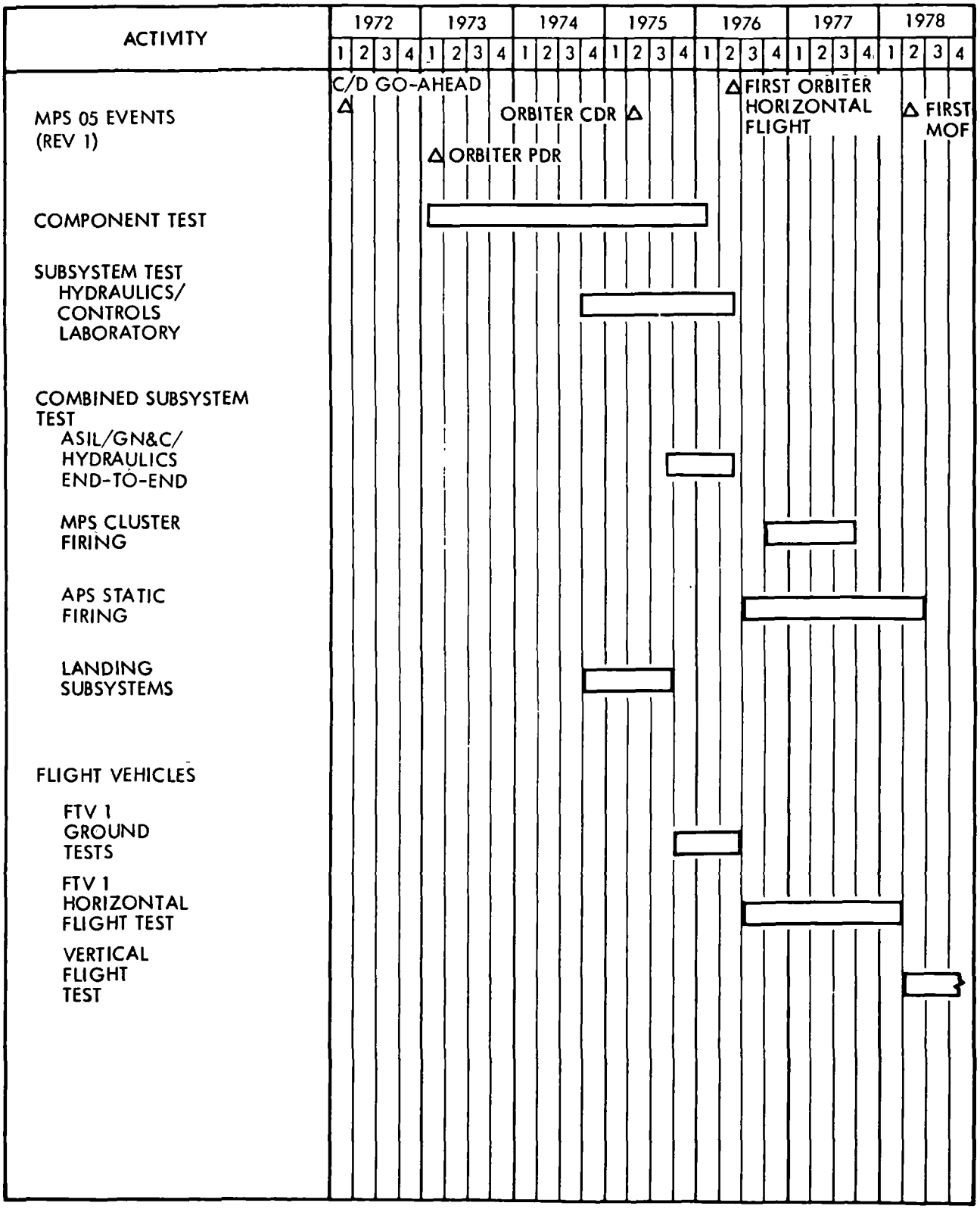


Figure 5-20. Hydraulic Power Subsystem Test Schedule

Table 5-13. Test Location Summary for Hydraulic Power Assemblies

Assemblies to be installed and tested at the hydraulics/controls laboratory:	
Hydraulic pumping assembly (4 systems) Main rocket engine actuators (2) OMS actuators (2) Elevons actuators (8) Rudder/drag brake actuators (4) Lines, valves, disconnects, servos, etc., associated with above.	
Assemblies to be installed and tested at locations other than, or in addition to, the hydraulics/controls laboratory:	
Hydraulic Power Assembly	Where Tested
Nose landing gear	Landing gear test facility
Main landing gear	Landing gear test facility
Wheel brakes, anti-skid, steering	Subcontractor test facility
Cargo door	Ground test of flight test vehicle
Turbofan engine rotation	ABES deployment fixture
Main engine actuators	MPS cluster test
OMS actuators	APS static firing

Table 5-14. Hydraulics/Controls Laboratory Test Article Requirements

Assembly	Quantity
Elevon actuation	100 percent
Rudder actuation	100 percent
Speed brake actuation	100 percent
MPS gimbal actuation	100 percent
OMS gimbal actuation	100 percent
Main gear actuation	-
Nose gear actuation	-
Nose gear brakes/steer	-
Main gear brakes/skid	-
Hydraulic power generation	100 percent
Fluid distribution	100 percent
Actuator assy and data bus	5 percent
Flight control drivers	50 percent

Notes:

1. The hardware quantities identified are for subsystem level testing, and do not include requirements for development or qualification of individual components and subassemblies.

2. This test article is also used for G/N&C hydraulics end-to-end tests described in Section 6.2.

Table 5-15. Hydraulic Power Subsystem Test Support Requirements

Item	Requirements
Facility	Electrical power - 60-cycle three phase - 120, 440, 4160v; 400-cycle three phase 120v; 29vdc (4160v for hydraulic pump drive motor) Water - fire extinguisher, potable GN_2 storage transfer He storage transfer Air conditioning/heating, ventilation Weatherproof test area
Support equipment	Control/simulation/data acquisition computing capability Vacuum pump Electric motor driven variable speed drives for hydraulic pumps Hydraulic loops servicing Ground hydraulic power Programmable loads for elevons, rudder/speed brakes, gimbals, etc. Test gas distribution/regulation Structure, to simulate orbiter, for support of test article hydraulic subsystem Test control console ASIL interface Hydraulic fluid cooling

Table 5-15. Hydraulic Power Subsystem Test Support Requirements (Cont)

Item	Requirement
Software	Programs to implement following: Control of test sequence Control of simulated loads Data acquisition Simulation of DCM Test reporting CRT display of test data Data analysis

Note:

The requirements identified are for subsystem level testing, and do not include requirements for development or qualification of individual components and subassemblies.

5.6 GUIDANCE, NAVIGATION, AND CONTROL (GN&C) SUBSYSTEM

5.6.1 Description

The orbiter GN&C provides inputs to the DCM which are derived from attitude, attitude rate, acceleration, air data, RF navigation sensors and manually generated crew inputs. The DCM performs targeting, navigation calculations, navigation data filtering, and control law generation. The GN&C also plays a role in the execution of commands outputted from the DCM by providing ACPS jet selection logic, engine command logic, and aerosurface and thrust vector control servo electronics.

The baseline GN&C subsystems derives inputs from five independent sensors: IMU, strapdown star tracker, precision ranging system (with ground and space station transponders), air data system, and rate sensors.

Triple redundant IMU's are used, each consisting of two LRU's, the platform and the power supply. The platform has four gimbals with the inner member being the stable element. The stable element contains two conventional gyros, one controlling the yaw and roll platform gimbals and the other controlling the pitch gimbal axis. Also mounted on the stable element are two accelerometers, one a single-axis accelerometer measuring Y-axis accelerations while the other is a two-axis accelerometer measuring accelerations in the X and Z axis.

The star tracker is a strapped-down optical sensor using an electronic scan to determine star positions within its eight-degree field of view. When compared with star position data stored in DCM memory, the true attitude of the orbiter may be determined for IMU alignment and subsequent maneuvers. The star tracker may also be used for tracking a beacon light on the space station.

The precision ranging system consists of triple redundant transceivers located on board, globally located transponders, and a transponder on the space station. With this arrangement, range and range rates can be determined between the orbiter and any given transponder within line of sight. When multiple transponders can be simultaneously interrogated, position update can also be derived. This system will be used to navigate, rendezvous, and augment the automatic landing function.

The air-data system consists of air-data packages and sensors. Three air-data packages are provided for FO-FS fault tolerance, each consisting of five pressure transducers and associated electronics. Each requires seven pressure inputs to measure: total pressure, subsonic static pressure, supersonic static pressure, angle of attack, angle of sideslip.

The baseline rate sensor is of the vibrating-wire variety of which nine are used: three each on the pitch, yaw, and roll axis. Properly located throughout the vehicle, these sensors will provide the basic vehicle rate data in addition to sensing body bending.

Figure 5-21 shows subsystem elements, and Figure 5-22 is the subsystem schematic.

5.6.2 Requirements

The GN&C subsystem test requirements (Tables 5-16), have been categorized by certification requirements.

5.6.3 Approach and Rationale

The approach and rationale to be used in the development of the GN&C are presented in the test logic and constraint network, Figure 5-23. It is noted that horizontal flight is constrained by qualification of Criticality I hardware and integration of the GN&C with the aerosurface flight controls in the ASIL/hydraulics controls laboratories. Vertical flight is constrained by integration of the GN&C with the MPS and APS for TVC tests during the static-firing programs. Also indicated is the acceptance/checkout flow of production hardware.

GN&C subsystem development will begin with computer simulations of the end-to-end flight control system. The only actual hardware will be a cockpit mockup and pilot controls. Visual presentations will enable evaluation of subsystem gains and the ability of the pilot to fly the vehicle. Data from these simulations will enable development of landing, navigation, and guidance techniques. The data will also provide the basic requirements for subsequent hardware and software design. The certainty of data obtained during simulation is a function of the fidelity of the computer model; therefore, as the engineering models of the components and assemblies become available, test articles will evolve into actual subsystems with only interfaces being simulated. Finally as a prerequisite to flight, simulation must be eliminated from the test article. This can only be done by end-to-end testing of the variety described in the combined subsystems test program (Section 6 of this volume) and by ground testing of the first flight vehicle.

Combined system tests will verify time delays, phase relationships, and frequency response for the aerodynamic control and thrust-vector control system elements. This will be accomplished by interconnecting the avionics subsystem integration laboratory (ASIL) with the hydraulics/controls laboratory for end-to-end testing of the flight control system and providing enough of the avionics to the static firing programs for evaluation of TVC and rocket engine discrete control.

EMC/EMI will be evaluated at the LRU, subsystem, and combined subsystem levels and will be a key development issue on the first flight vehicle. Finalization of certain aspects of the GN&C are dependent on test data obtained later in the program. Final determination of the effect the body contour has on the air data sensors will be made during flight test, and knowledge of body bending resonant frequencies will be gained during ground vibration testing. Data from these tests will be fed back through design for finalization of software and hardware configurations.

During the in-process checkout phase, subsystem installation will be functionally verified to detect and correct subsystem installation anomalies. Functional checkout will be accomplished on any portion of the subsystem which is not readily accessible after the major vehicle subassemblies are mated. A schedule of events leading to subsystem certification is presented in Figure 5-24.

5.6.4 Test Article Requirements

Table 5-17 delineates test hardware which will be used for subsystem level R&D testing and, when feasible, reused for combined subsystem testing.

5.6.5 Support Requirements

Table 5-18 delineates the support requirements for subsystem level R&D testing and vehicle level in-process checkout.

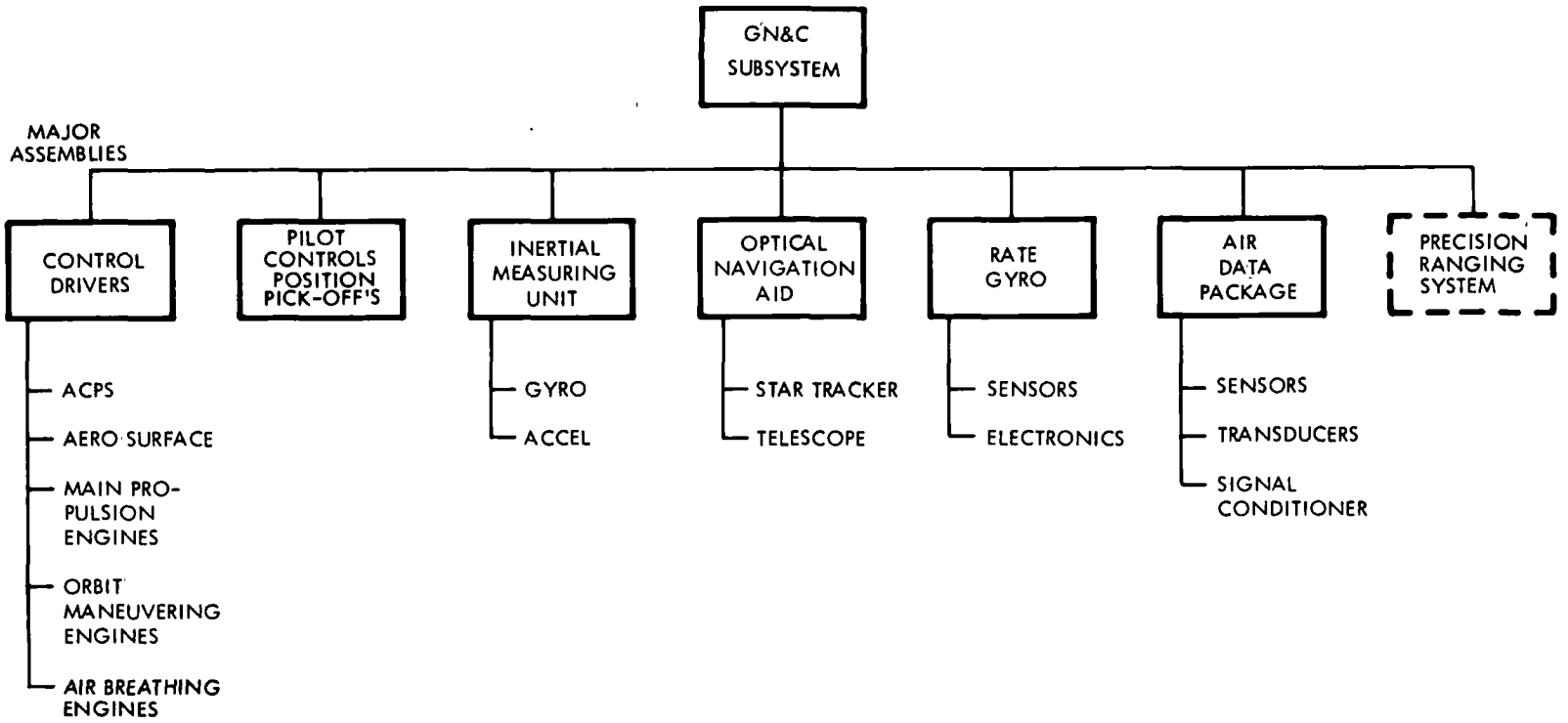


Figure 5-21. Guidance, Navigation, and Control Subsystem Elements

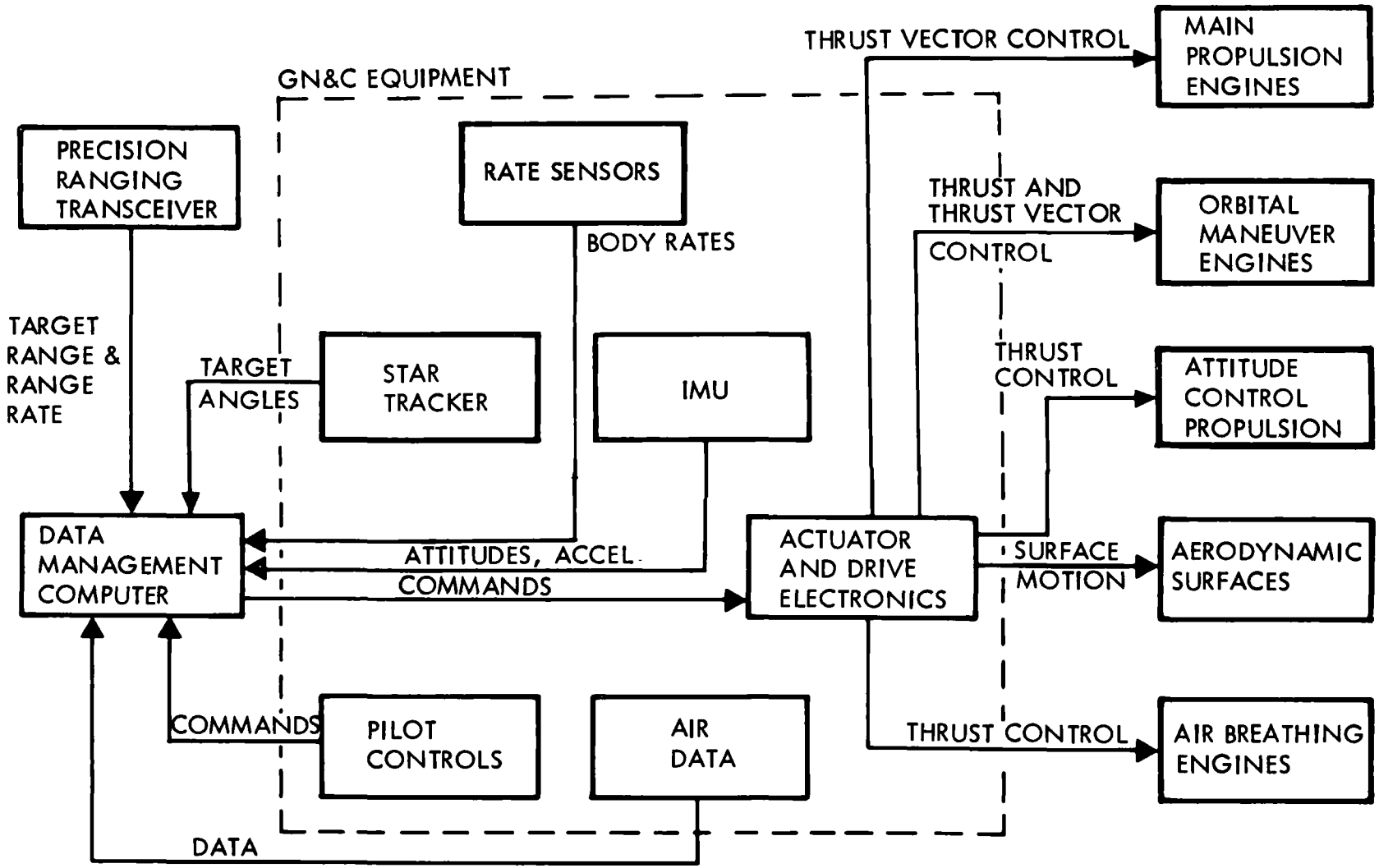


Figure 5-22. GN&C Subsystem Schematic

Table 5-16. Guidance, Navigation, and Control Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
OPERATIONAL REQUIREMENTS							
1. Adequacy of cooling system to maintain GN&C subsystem assemblies within temperature limitations						P	S
2. Warmup time required to obtain stable operation of IMU.				P			
3. IMU gyrocompassing prelaunch alignment technique					P		
4. Capability to remove and replace individual LRU's with minimum effort for maintenance	P						S
5. Capability of reconfiguring the GN&C to the various modes via the flight-control panel						P	S
6. Capability to make navigation and docking sightings within the required limits via the telescope						P	S
7. Capability of maintaining IMU drifts within requirements during boost and vibration				P			S
8. Accuracy of reference alignment between airframe and IMU and star-tracker base frame	S						P
9. Capability of switching from automatic flight mode to manual take-over					P	S	
10. Capability of commanding abort						P	S
11. Ability of all GN&C subsystem elements to operate within performance tolerances while under environments specified			S	S			P

Table 5-16. Guidance, Navigation, and Control Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GN&C							
1. Capability of the body rate sensors to provide body rate data at the required frequency limits and amplitudes			S			P	
2. Capability of the IMU to provide within required accuracies, incremental measurements of vehicle velocity and attitude information					P		S
3. Effectiveness and accuracy of the air data sensors			S			S	P
4. Minimum impulse capability of the GN&C in conjunction with the ACPS						P	S
5. Capability of main engine gimbal control within accuracy requirements to maintain proper boost guidance						P	S
6. System gains in the pitch, roll, and yaw control loops	S					P	S
7. Stability of the control loops using the frequency response method						P	
8. Capability of air data sensing to provide dynamic pressure, angle of attack, sideslip angle, Mach number, barometric altitude, calibrated air speed, total pressure, static pressure, and differential pressure within accuracy requirements				P			S
9. Adequacy of flight control loop data sampling rates for performing critical flight maneuvers						S	P
10. Proper gain scheduling limits and switching times for boost load relief	S					P	
11. Switching from load relief to attitude hold with minimum transients						P	S
12. Control system deadbands						P	S

Table 5-16. Guidance, Navigation, and Control Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GN&C (Cont)							
13. Capability to control delta-V maneuvers						P	S
14. ACPS jet selection logic						P	
15. Digital fly-by-wire flight control system.						P	S
16. Redundancy management capability	S					P	
17. Capability of rotation controller to provide velocity and acceleration commands						P	S
18. Capability of rotation control to control surfaces during aerodynamic flight						S	P
19. Capability of translation controller to provide commands to the translation jets						P	S
20. Attitude hold mode capability						S	P
21. Ability of GN&C to perform rendezvous maneuvers					S	S	P
22. Ability of GN&C to perform deorbit maneuvers					S	S	P
23. Ability of GN&C to perform reentry maneuvers					S	S	P
24. Ability of GN&C to provide stability during hypersonic and subsonic flights						S	P
25. Automatic and manual landing capability						S	P
26. Pitch control blending of ACPS and aerosurfaces						S	P
27. Automatic cruise control						S	P
28. Handling qualities						S	P

Table 5-16. Guidance, Navigation, and Control Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GN&C (Cont)							
29. Capability of the driver units to provide control of valve solenoids and ignitors control of ACPS and OMS engines and proportional control of hydraulic engine gimbal actuators						S	P
30. Capability of the star tracker to provide altitude update for navigation and bearing information for rendezvous						S	P
31. Capability of display three-axis altitudes and attitude rates for manual control purposes						S	P
32. Capability of air-breathing engine throttle control						S	P
33. Capability of the GN&C power distribution to provide the required special voltage levels and frequencies.				S	P	S	
34. GN&C software		S				P	S
INTERFACE REQUIREMENTS							
1. Capability of acquisition, control and test unit (ACT) to communicate with the GN&C LRU's and the computer via the data bus						P	S
2. Capability of the data management computer to provide for automatic sequencing, configuration control, IMU initialization computation, attitude determination, gimbal control of MPS, ignition control of OMS and ACPS, thrust control of ABES, aerodynamic surface control, GN&C display data computations, and checkout and fault isolation of GN&C system						P	S
3. Reentry and boost guidance						P	S
4. Capability of the radar altimeter to provide altitude and altitude rate with required tolerance to effect automatic landing						S	P

Table 5-16. Guidance, Navigation, and Control Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
INTERFACE REQUIREMENTS (Cont)							
5. Capability of the precision ranging transceiver to provide navigational data for vehicle state vector update and rendezvous and auto landing						S	P
MISCELLANEOUS							
1. Verify compatibility of GN&C with instrumentation.						P	
2. Verify compatibility with SE						P	S
3. Verify compatibility with electromagnetic interference/ susceptability requirements			S	S		P	S
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Continuity of electrical circuit paths, "as built" equals "as designed"							P
2. Integrity of harness wiring insulation							P
3. GN&C components in the forward, intermediate, crew compartment, and aft fuselage are compatible with, and can be controlled by the DCM system							P
4. Proper operation of the flight control computer, inertial measuring unit, rate sensors, and air data preprocessor							P

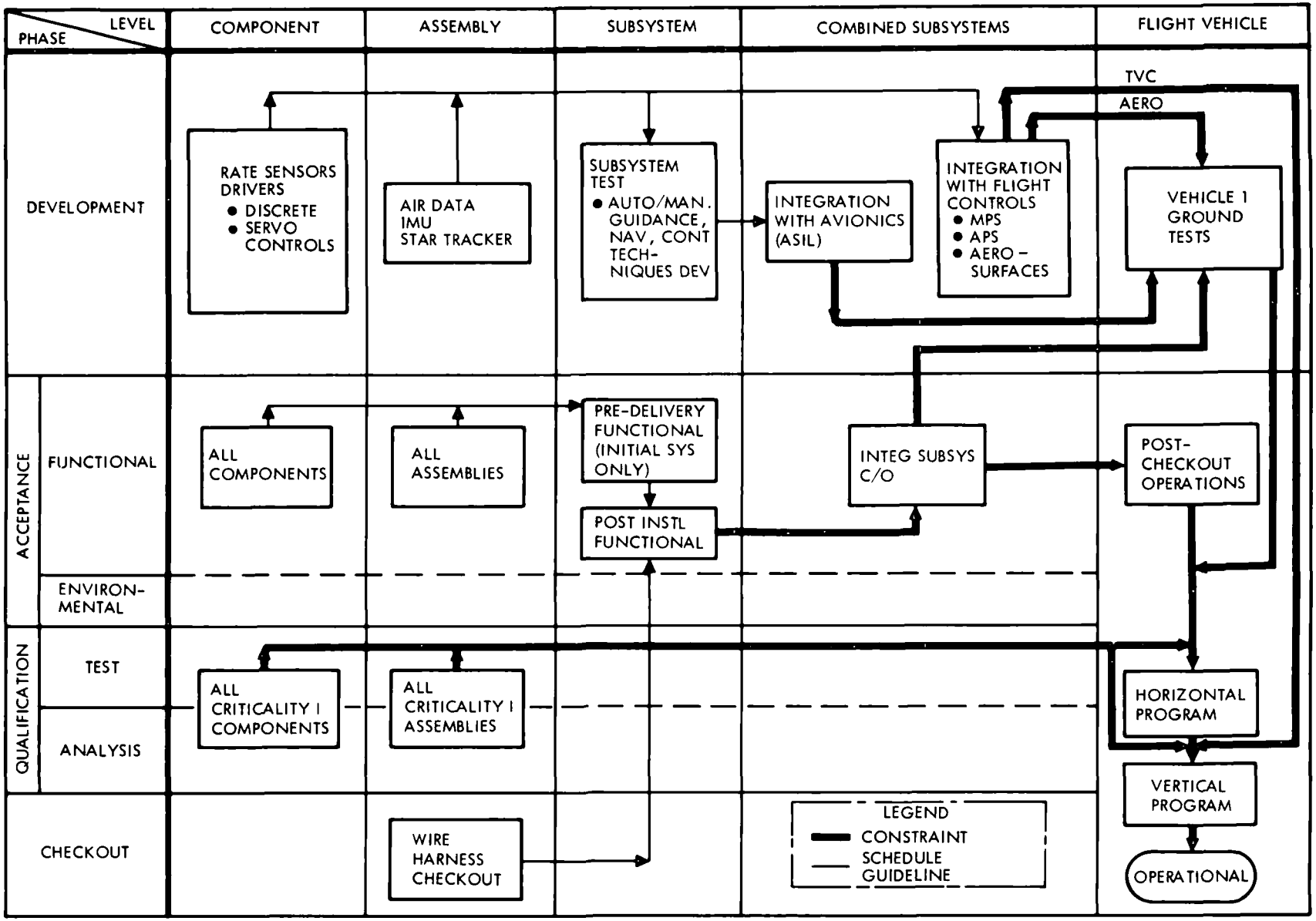


Figure 5-23. GN&C Test Logic and Constraint Network

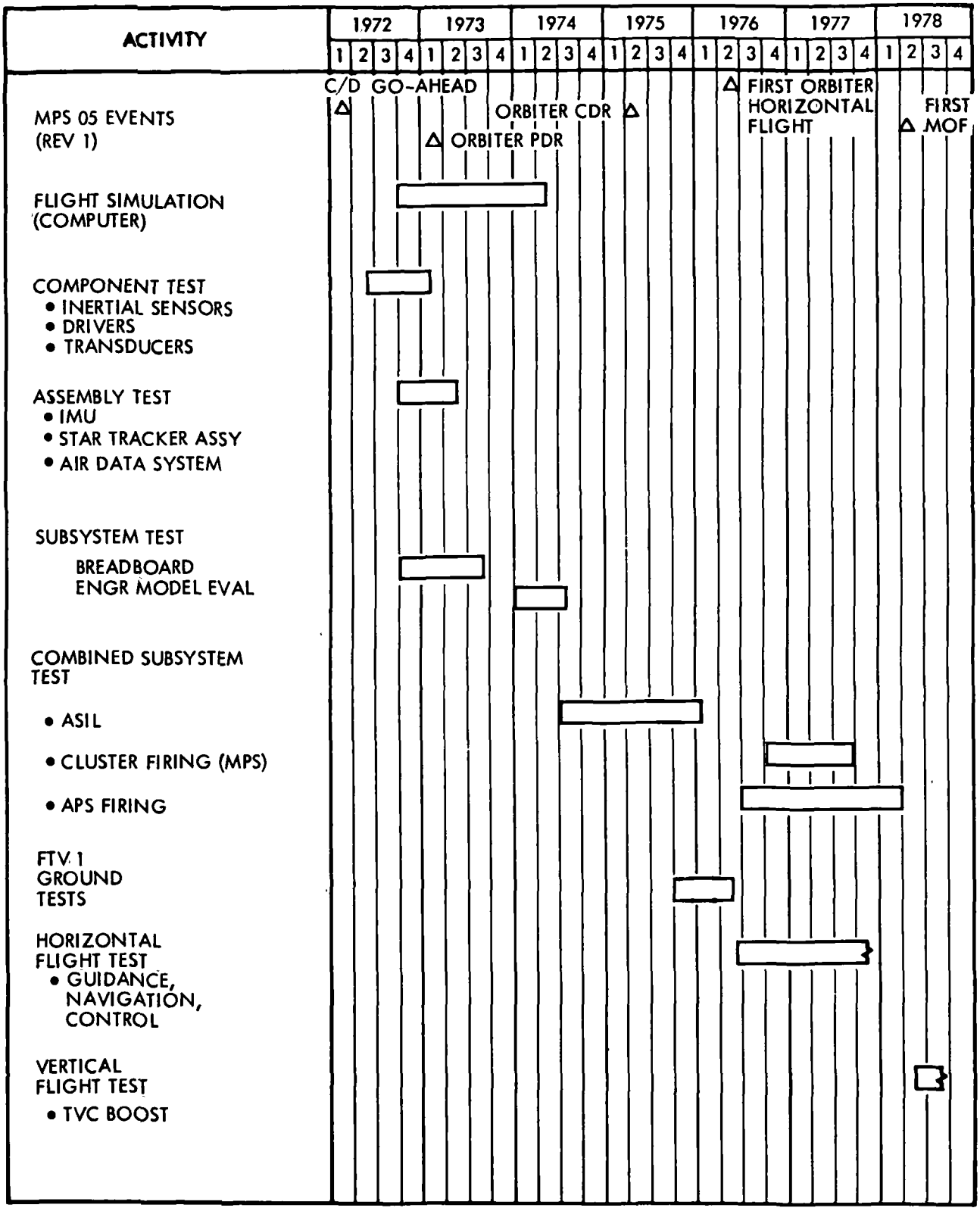


Figure 5-24. GN&C Subsystem Test Schedule

Table 5-17. GN&C Subsystem Test Hardware Requirements

Component or Assembly	Quantity	
	Computer Simulation	Subsystem Testing
IMU and power supply	N/R	3
Air data system		1
Rate sensors		100 percent
Star tracker assembly		1
Control drivers		100 percent
ACPS/OMS (discrete)		
Aero surfaces/MPS/OMS (TVC)	N/R	
Pilot controls position transducers	100 percent	100 percent
Throttle position		
Hand controllers		
Pedal position		
Other		

Note:
The hardware quantities identified are for subsystem-level testing (contractor and subcontractor), and do not include requirements for development or qualification of individual components and subassemblies. Contractor-utilized subsystem test hardware will be reused during ASIL combined subsystem testing.

Table 5-18. GN&C Subsystem Test Support Requirements

Item	Requirements
Facility	Electrical power 120 volts, 3 phase, 60 Hz 120/208 volts, 3 phase, 400 Hz 28 volts d.c. regulated Capability to support environmental test Air conditioning/heating/ventilation
Support equipment	Test control console Miscellaneous environmental test equipment (including EMI) Flight deck mockup Simulated visual presentations for landing simulation and rendezvous and docking Star field presentation for star tracker Dynamic simulators for IMU and rate sensors Control/simulation/data acquisition computing capability Cooling and circulation unit (for coldplate network) Electrical ground power and distribution Automatic circuit analyzer Optical alignment set Electrical cable set
Software	Programs to implement following: Control of test sequence Simulation of flight control system Control of dynamic simulators Simulation of DCM Data acquisition and reduction to engineering units Test reporting

5.7 DATA AND CONTROLS MANAGEMENT (DCM) SUBSYSTEM

5.7.1 Description

The data and controls management (DCM) subsystem acts as the integrating agent for all vehicle subsystems. The subsystem consists of hardware and software to implement the following functions.

1. Configuration Control and Sequencing. Provides control over primary and redundant elements of subsystems for both normal and contingent operations.

2. Display and Control Data Formatting. Provides the basic interface between the subsystems and displays and controls used by the crew; processes data for display and commands for transmission to the subsystems.

3. Guidance and Navigation Computation. Performs calculations and logical analysis for solution of guidance and navigation problems for use by the crew and/or input to the flight controls.

4. Flight Control. Receives data from the input controls and/or the guidance and navigation subsystem and acts as a communications media with the propulsion subsystems and/or aerodynamic controls for commands/responses.

5. Data Storage. Receives and stores selected data on subsystem status and performance.

6. Data Acquisition and Distribution. Acquires information from subsystems and distributes it for storage or other processing.

7. Checkout and Fault Isolation (COFI). Monitors selected parameters of each subsystem on a scheduled and interrupt basis; performs logical analysis to verify subsystem status; in the event of malfunction, isolates the fault and alerts the crew, and/or completes automatic switchover to the redundant element.

8. Self-Management. Monitors status of its own hardware elements and will complete automatic switchover to a redundant element in the event of a malfunction.

Major elements of the DCM hardware and software systems are shown in Figure 5-25. Basically, the system consists of the data management computers, where logical analysis, manipulation of data, and program

execution take place; the mass memories, where programs and data are stored; the data bus, which acts as the communications media between the DCM and other subsystems; and the software, which implements DCM functions. Figure 5-26 shows the general arrangement of DCM hardware.

The checkout capabilities of the DCM subsystem are described in Table 5-19 which is derived from a preliminary allocation of functions between the on-board and ground systems. The functions discussed relate to ground checkout and operations only.

5.7.2 Requirements

Test requirements for the DCM and related software are an output of detailed review of hardware and software design and performance requirements. They are summarized below.

1. Central Processing Unit (CPU). Verify capability to address main storage, collect and store information, process equations, execute sequential instructions, process interrupts, and initiate communications between main storage and the input/output devices.

2. Input/Output Units (I/O). Verify ability to handle communications between the CPUs and all vehicle LRUs, other CPUs, and mass storage via the data buses and/or dedicated hardlines.

3. Main Storage Unit (MSU). Verify ability to access and store required memory locations within specified time intervals.

4. Data Bus. Verify capability to act as communications media between major elements of the integrated avionics (IAS), the IAS, and other orbiter subsystems; between the booster and orbiter; and between the shuttle and the ground support equipment.

5. Mass Memory Unit (MMU). Verify functional capability to store and retrieve operational programs, special checkout programs, fixed display formats, checkpoint restart data, error history files, and subsystem performance data.

6. DCM System Software. See Volume V for test requirements. These include flight and ground tests for both airborne and ground support hardware; Volume V also covers test of the DCM software.

The DCM subsystem test requirements, given in Table 5-20, have been categorized by method of verification.

5.7.3 Approach and Rationale

The DCM requires a significant amount of software to function. Development and qualification of software, therefore, are major tasks within overall development of the DCM (for development logic see Figure 5-27). The DCM computers and the mass memories will be adaptations of off-the-shelf hardware, and no significant development risks are anticipated. Since the DCM exerts varying degrees of control, management, and data recording for all other subsystems, integration with these subsystems becomes a necessary and significant task. The integration task has several aspects, including the following:

1. Integration of elements of the DCM
2. Integration of the DCM with other avionics and with software
3. Integration of the DCM, avionics, and software with nonavionics subsystems
4. Integration of the DCM with support systems
5. Integration of booster and orbiter DCM.

The logic diagram (Figure 5-27) shows that testing will start at a subassembly level for hardware and in a simulator laboratory for the software. Elements of the DCM and software will be first integrated at an avionics systems integration laboratory (ASIL), followed by integration of all elements of the avionics and software. During this period, integration of avionics/nonavionics with software will take place. Final verification of the DCM and software will take place during the horizontal and vertical flight test program. Underlying logic for the DCM test program will be discussed by considering requirements for initial development testing, avionics integration, and avionics/nonavionics integration.

1. Initial Development Testing. Basic system operating algorithms must be developed and iteratively tested prior to any hardware or software detailed design. This should take place early in the program with modern computer simulation and modeling techniques. Outputs from this activity will be used as a basis for subsequent design of DCM hardware and software, and will establish DCM interface requirements for all other vehicle subsystems. Issues cited for "Computer/Model" testing in Table 5-20 will be addressed during this phase.

2. DCM Development and Integration. Although the Basic CPU and mass memory will be off the shelf, a significant amount of adaptation, new equipment, and new software will be required The CPU, mass memory, data bus, and other hardware elements must be integrated with the software to form a working system. This integration will take place at an avionics systems integration laboratory. Issues designated for "Subsystem" testing in Table 5-20 will be certified during this phase.

3. DCM Integration and Software with Other Avionics. During the period that the DCM is being developed, other avionics subsystems will also undergo their respective development programs. Generally, the GN&C, EPDC, COMM, and D&C will be developed in other specialized areas of the ASIL. As the various avionic subsystems reach maturity in their development, they will be integgrated with the DCM in the ASIL. The first avionics subsystem to be integrated with the DCM must be the displays and controls. This is necessary to provide the input/output devices required to interface the DCM with the crew. (Reference: "Combined Subsystem" issues on Table 5-20.)

4. Integration of DCM, Other Avionics, Software, and Nonavionics Subsystem. The avionics and software must be integrated with all other vehicle subsystems. (Reference: "Combined Subsystem" test category items in Table 5-20.) Alternatives relevant to this issue include accomplishing avionics/nonavionics integration on a ground test vehicle or deferring this integration until ground testing of the flight vehicles. A compromise solution was chosen; i.e., to integrate real avionics hardware and software with computer or breadboard models of the nonavionics subsystems in the ASIL. This integration would be extensive and comprehensive and would be followed by less extensive testing with real nonavionics hardware on a flight vehicle. Certain phases of GN&C testing, however, do require integration of avionics with real hydraulics/controls hardware (for GN&C end-to-end tests as an example). This requirement will be satisifed by electrically connecting the hydraulics/controls laboratory with the ASIL. The hydraulics/controls laboratory is described in Section 5.5. A schedule showing major milestones for DCM development is given on Figure 5-28.

5. Hardware Acceptance Checkout. Interconnecting wiring will be installed and tested in each of the major sections of the orbiter. After the major sections are assembled and final interfaces are checked, the DCM will be tested.

6. Software Acceptance Checkout. To verify proper operation, software must be tested with actual or simulated hardware. The testing should cause the software to exercise all possible contingencies that are called for in the software specification in as realistic an environment as possible. Since the all-contingencies testing is generally not possible with real hardware, computer simulations will be used where required. In general, programs will be verified in three stages: detail test of individual modules, higher level tests of combinations of previously verified modules, and finally, gross tests integrating several subsystem level software module groups, using ASIL avionics and support equipment.

5.7.4 Test Article Requirements

DCM hardware test article requirements are summarized in Table 5-21.

5.7.5 Support Requirements

Two facilities are required for testing of the DCM, a simulation laboratory for predesign and the avionics system integration laboratory (ASIL) for integration tests. (This does not include any laboratories that might be required by suppliers for development or adaptation of purchased hardware or software.) All avionics will be tested and integrated at the ASIL, which is shown in block diagram form in Figure 5-29. Note that computer or breadboard models may be used to simulate nonavionics subsystems. The hydraulics/controls laboratory is shown in phantom because it is used in conjunction with the ASIL for GN&C end-to-end tests. Ordinarily, the hydraulics/controls laboratory is an independent entity. (See Table 5-22.)

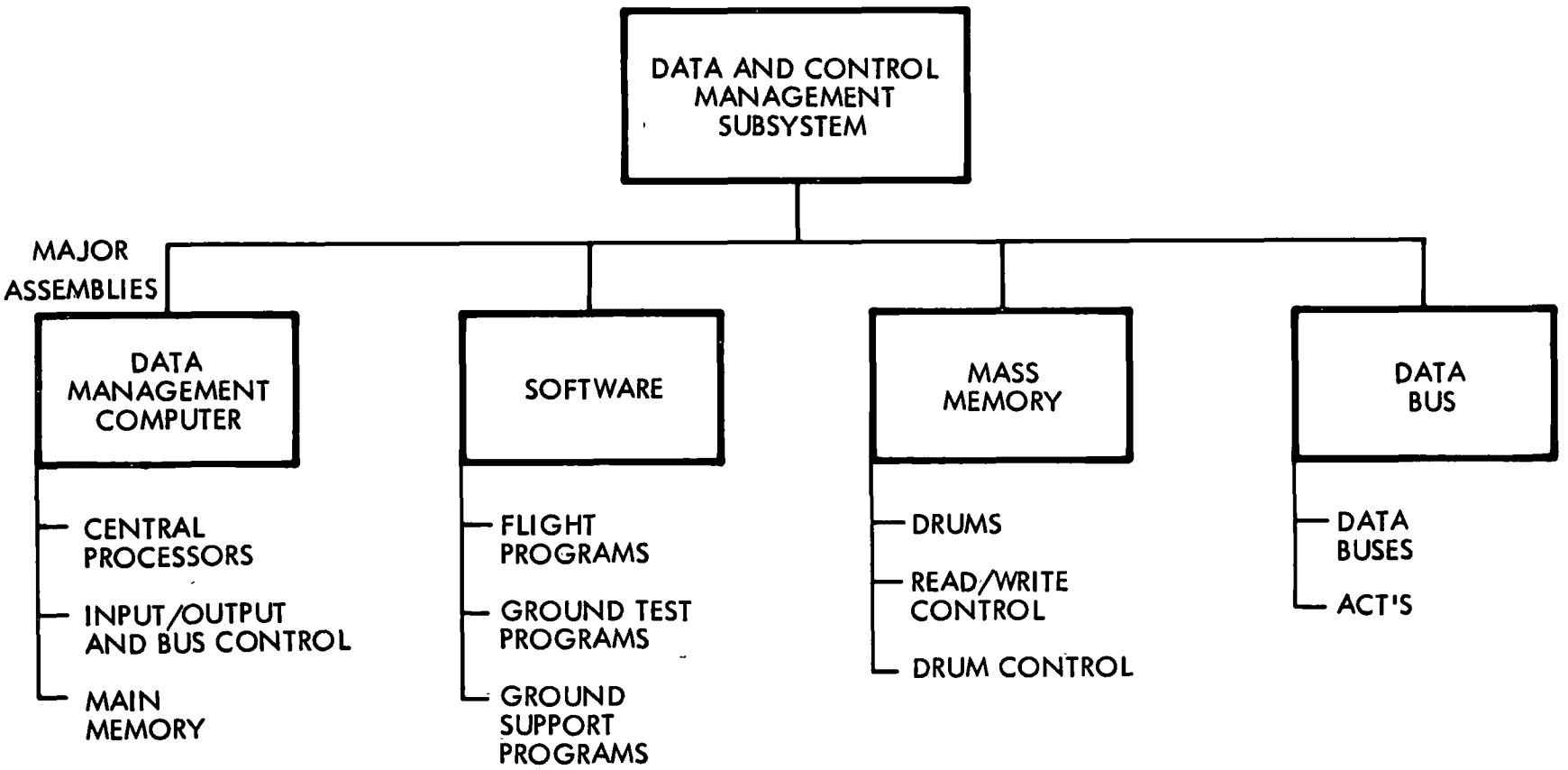


Figure 5-25. Data and Control Management Subsystem Elements

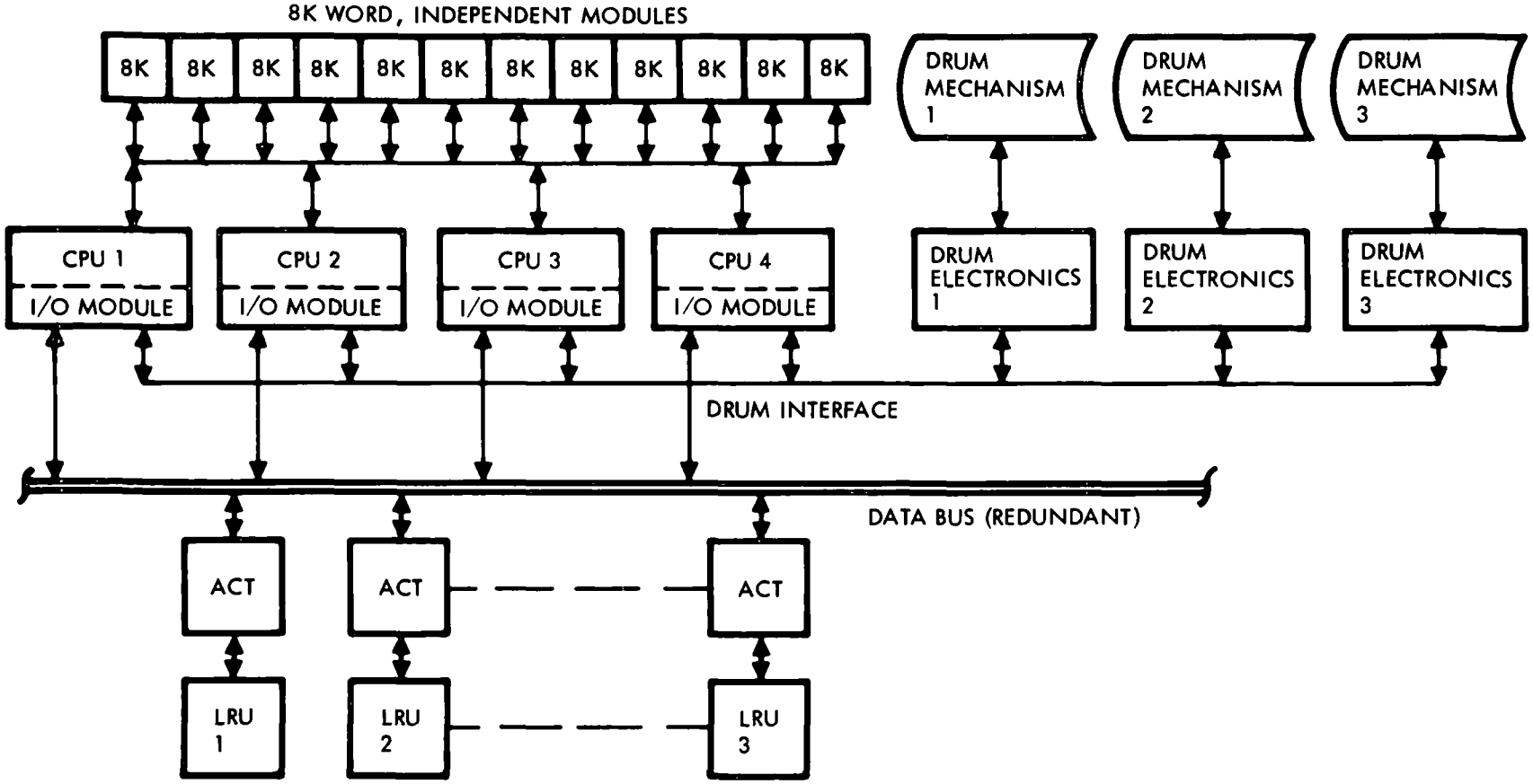


Figure 5-26. DCM Hardware Schematic

Table 5-19. Preliminary Allocation of Functions, Ground Versus On-Board Operations

Phase \ Function	Verify Wire Harness Integrity	Verify Fluid Installation Integrity	Verify Bus Isolation	Coax Installation Integrity (VSWR)	Service Fluid Loops	Provide Electrical Power	Provide Hydraulic Power	Provide Cooling	Load Software	Verify Software Load	Subsystems Activation	Subsystems Shutdown	Timing Update (via UDL)	Align Engines and Aero Surface	Align Optical Devices	Stimulate Inertial Sensors	Stimulate Flight Control System	Stimulate Star Tracker	Stimulate RF Navigation Aids	Subsystem Performance Monitoring	Payload Status Check	Demodulate Vehicle RF	Provide Subsystem Display and Controls	Display Checklist	Perform Simulated Mission Sequencing	Service Consumables	Provide Power Gen Gaseous Reactants	Monitor Hazardous Elements (pressure vessels, etc)	Perform IMU Alignment	Data Review	Verify Ordnance Systems	Propellant and Reactant Loading	Control Vehicle Compartments Purge	Control Tanks and Lines Purge	Store Performance and Checkout Data
In-process Checkout - Manufacturing	G	G	G	G	G	G	G	G	G	O				G																G					
Subsystem Checkout - Manufacturing						G	G	G	G	O	G/O	G/O	G	G	G	O	O	G	G	O		G	G/O						O	G	G/O				G/O
Dry Integrated Checkout - Manufacturing						G	O	G	G	O	O	O	G			O	O	G	G	O		G	G/O		G/O				O	G					G/O
Hot Fire Integrated Checkout - Manufacturing						G/O	O	G/O	G	O	O	O					O			O		G	O			G	G	O		G		G/O	G	G/O	G/O
Preflight Checkout - Horiz						G	G	G	G	O	O	O	G		G	O	O		G	O		G	O	O		G		O	O	G		G/O			G/O
Preflight Checkout - Ferry						G	G	G	G	O	O	O	G		G	O	O		G	O		G	O	O		G		O	O	G		G/O			G/O
Premate Checkout						G	G	G	G	O	O	O	G		G	O	O	G	G	O	G	G	G/O		G/O				O	G	G/O				G/O
Post Flight Safing						G	G	G				O								O	O	G	G/O	O				G/O		G			G	G/O	G/O
Maintenance Retest	G	G	G	G	G	G	G	G	G	O	O	O	G	G	G	O	O	G	G	O		G	G/O				G		O	G	G/O				G/O
Vehicle Static Fire						O	O	G	G	O	O	G	G				O			O			G		O	G	G	O		G		G/O	G	G/O	G/O
Prelaunch						G/O	G/O	G	G	O	O	O	G		G	O	O	G	G	O	O	G	G/O	O		G		G/O	O	G		G/O	G	G/O	G/O

NOTE: G Allocated to ground system
O Allocated to on-board system
G/O Accomplished jointly by ground and on-board systems

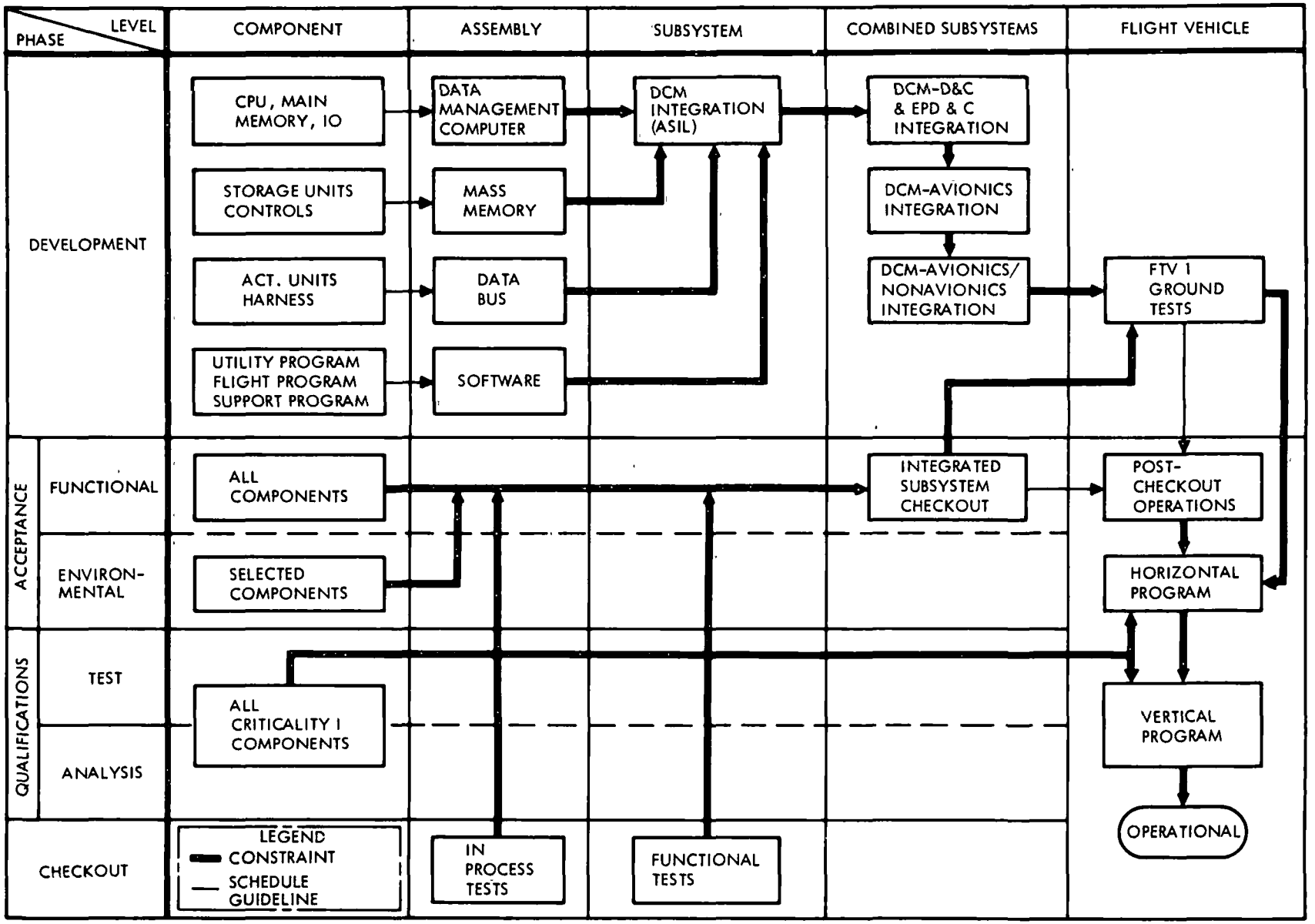


Figure 5-27. DCM Test Logic and Constraint Network

Table 5-20. Data and Controls Management Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
1. Integration of all hardware elements of the data control and management subsystem					P		S
2. Compatibility of DCM central processors, data bus, mass memory					P		
3. DCM computer performance in areas of register operation and manipulation and timing					P		
4. Addressing and access procedures for computer main storage and for mass storage		S			P	S	
5. Input/output facilities					P	S	
6. Throughput (overall processing rates)		S			P		
7. Instruction set, execution times, and instruction processing techniques					P		
8. Early version of executive software					S	P	
9. Synched-tandem operation of central processors		S			P	S	
10. Ability of DCM to manage its own redundant system		S			P	S	S
11. Interrupt facilities		S			P		S
12. Countdown clocks					P		S
13. Register management techniques		S			P	S	
14. DCM, pertinent display and controls, and flight program.						P	S
15. Ability to control DCM with displays and controls						P	S
16. Ability to interrogate and display registers with displays and controls						P	S

Table 5-20. Data and Controls Management Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
17. Integration of DCM with communications, GN&C and display/controls, and electrical power distribution and control subsystems		S				P	S
18. DCM and related software perform specified management, status monitoring, and data recording for other avionics subsystems		S				P	S
19. DCM redundant systems management capability		S				P	S
20. DCM operation under various in tolerance and out-of-tolerance power input conditions					P	S	
21. Functional interface between DCM avionics subsystems and avionics support equipment						P	S
22. Integration of DCM and software with nonavionics subsystems		S				P	S
23. DCM COFI capability						P	S
24. Functional interface between avionics subsystems and the displays/controls, ACPS, CMS, ABES, main engines, ECLSS, structure, hydraulics/controls, power generation and payload subsystems (includes integration of software)		S				P	S
25. Integration of avionics hardware with nonflight software						P	S
26. Integration of avionic hardware with various specialized versions of flight software						P	S
27. Integration of DCM with real shuttle hardware systems							P
28. Hardware interface between elements of avionics hardware and other nonavionics orbiter subsystems						P	S
29. Functional capability of DCM and related software to manage, control, monitor, and record data for other subsystems		S				P	S

Table 5-20. Data and Controls Management Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	1 Analysis	2 Computer/Model	3 Component	4 Assembly	5 Subsystem	6 Comb. Subsystem	7 Flight Vehicle
30. Ability of DCM computer to execute ground programs for checkout and other ground activity						P	S
31. Functional capability of DCM and related software to manage, control, monitor, and record data for vehicle subsystems in a horizontal flight mode						S	P
32. Functional capability of DCM and related software to manage, control, monitor, and record data for vehicle subsystems in an orbital mission mode						S	P
33. Capability of fly-by-multiplexed-digital-data bus approach affords stable and reliable control of the shuttle						P	S
34. Failure and recovery within the DCM, power generation, power distribution/control, GN&C or the hydraulics/controls does not cause excessive vehicle instability during any orbital or horizontal flight maneuvers						P	S
35. Interchangeability of DCM avionics hardware						P	S
36. Ability of DCM recovery capabilities						P	S
37. Ability of flight program to satisfy mission requirements in an operational environment						P	S
38. Integrated performance of avionics and related software in a fully operational environment						S	P
39. Compatibility between flight crew, integrated avionics, and software						P	S
40. Ability of DCM to support the automatic landing and precision ranging function						S	P
41. Functional interface between the DCM and ground computers and related software						S	P
42. Functional interface between the orbiter and booster DCM.							P

Table 5-20. Data and Controls Management Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
43. DCM computer and related software is capable of supporting:		S				P	S
a. Vehicle in-process and acceptance checkout							
b. Turnaround safing, maintenance, preflight checkout, and launch							
c. Rapid transfer of computer programming and mass memory data across the vehicle/ground system interface							
44. Ability of DCM and software to integrate the D/C, GN&C, and hydraulic subsystems for end-to-end operation of flight controls, during mission, and ground checkout modes						P	S
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Measurement of standing waves in DCM Data Bus immediately following data bus installation in the major subassemblies							P
2. Preinstallation checkout of buffers used to make DCM system compatible with other subsystems. Logic levels are applied and output is monitored for proper converted signal							P
3. Combined operation of DCM computer, mass memory, bus control unit, and data bus							P
4. Ability to control and monitor other DCM flight subsystems in the orbiter							P

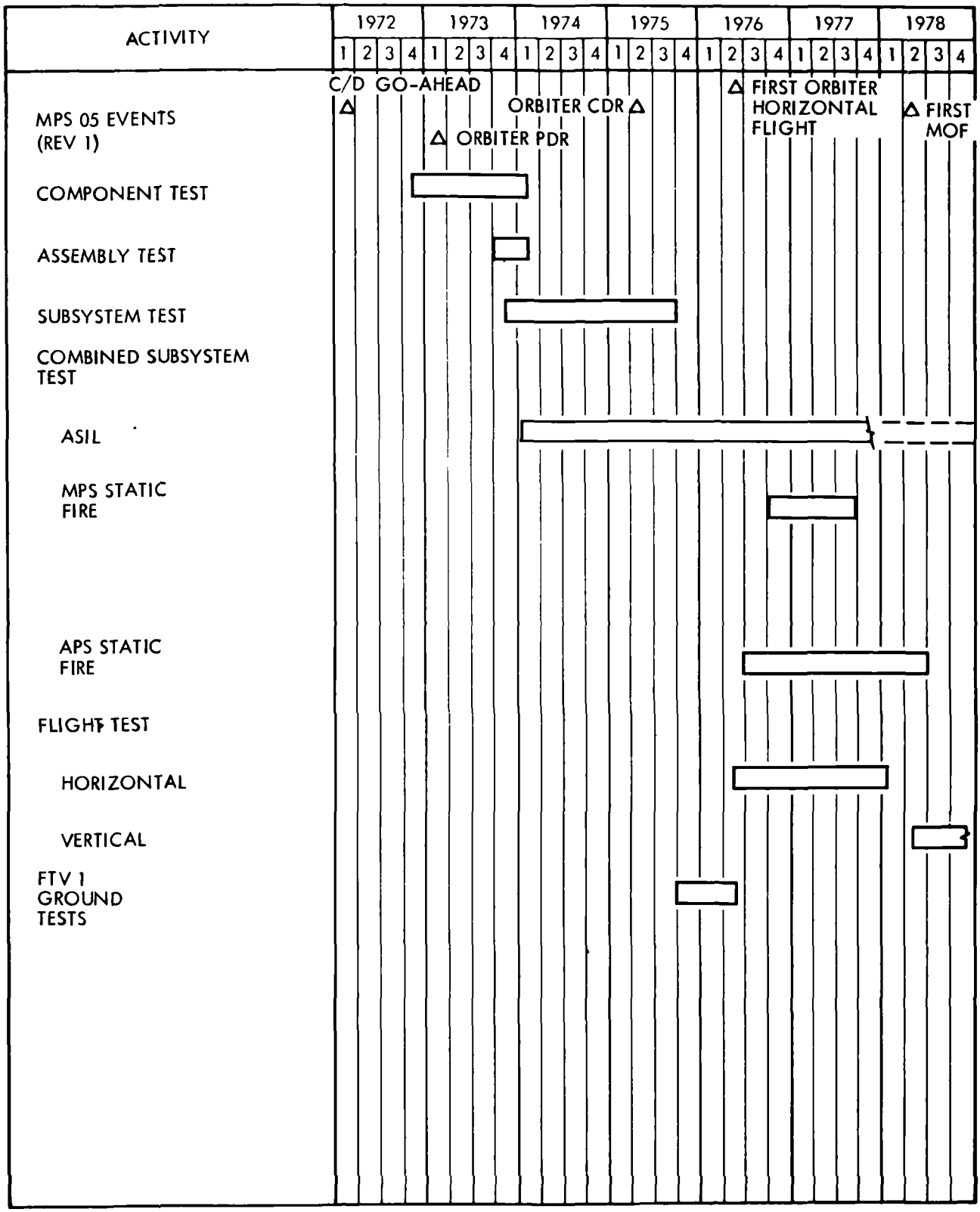


Figure 5-28. DCM Subsystem Test Schedule

Table 5-21. DCM Subsystem Test Article Requirements

Assembly	Quantity
CPU	3
Main storage	100%
Mass memory	100%
ACT assemblies	20%
Data bus harness	2

Note: The hardware quantities identified are for subsystem level testing, and do not include requirements for development or qualification of individual components and subassemblies. Articles listed will also be used in the avionics/nonavionics combined subsystem test program described in Section 6.2.

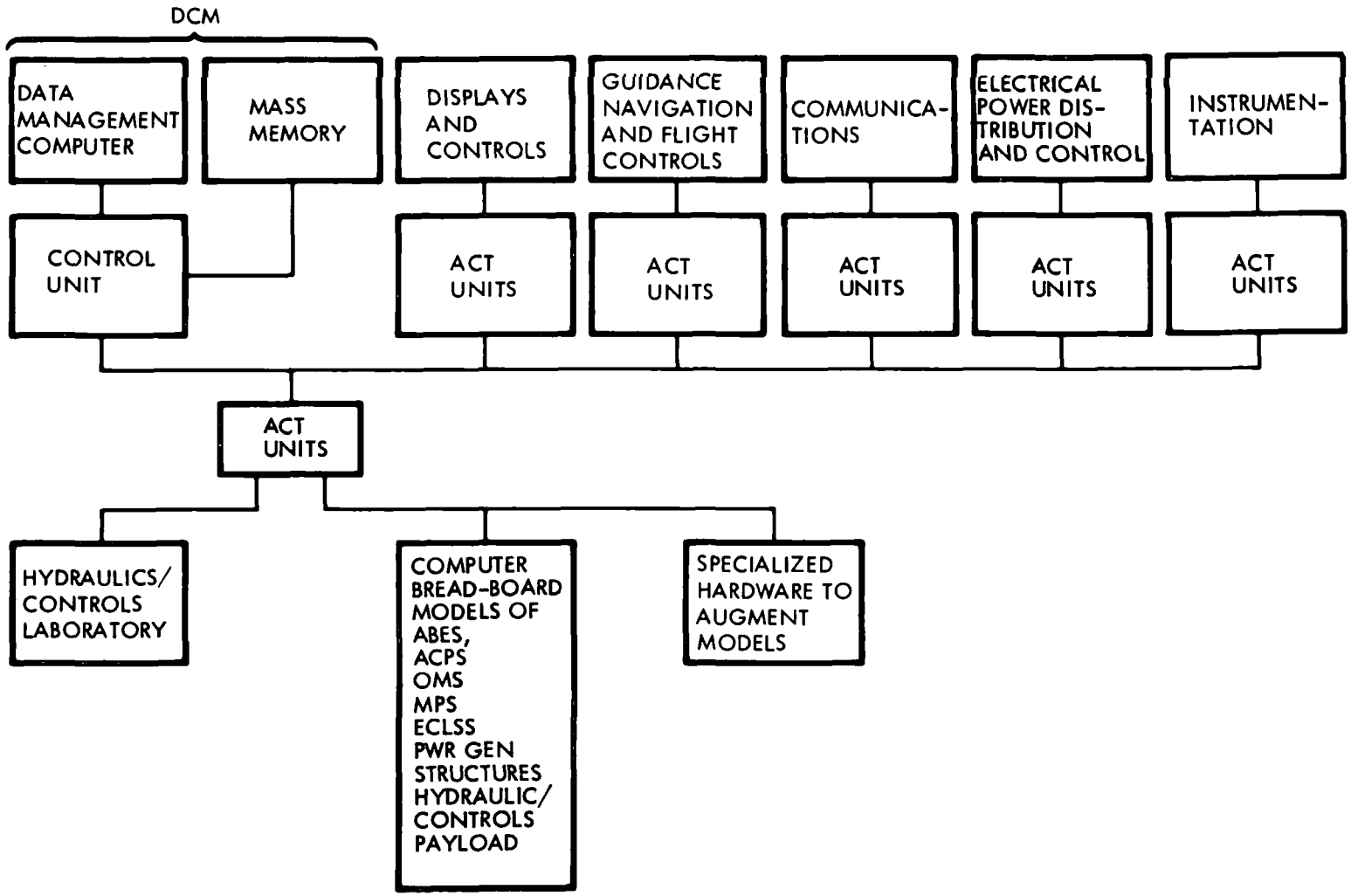


Figure 5-29. Avionics System Integration Laboratory Block Diagram

Table 5-22. DCM Subsystem Test Support Requirements

Item	Requirement
Facility	Electrical power - 60 Hz, three phase, 120 volts; 400 Hz, 3 phase, 120 volts; 28 volts dc Air-conditioning/heating/ventilation GN_2 supply and distribution
*Support equipment	Control/simulation/data acquisition computing capability Large general purpose computer Cooling and circulation unit (for coldplate network) Hardware simulations of specified nonavionics subsystems Miscellaneous environmental test equipment
**Software	Simulation programs for execution in large general-purpose computer. Miscellaneous dedicated test programs executed by and for test of DCM computers Initial version of DCM ground checkout programs Initial version of flight program system Programs for execution in support computer to implement the following: Loading of DCM computer Interfacing with DCM computer Simulating DCM computer Simulating selected nonavionics subsystems Controlling hardware simulators Controlling test sequence Data acquisition Test reporting Data analysis CRT display of test data

*The requirements identified are for subsystem level testing, and do not include requirements for development and qualification of individual components and subassemblies.

**Support items listed are also required for avionics/nonavionics combined subsystem tests described in Section 6.2.

5.8 DISPLAYS AND CONTROLS SUBSYSTEM

5.8.1 Description

The displays and controls (D&C) subsystem is a collection of equipment designed to: (1) to provide the flight crew the necessary information and command access to manage effectively the mission, the vehicle and its subsystems, and (2) to provide the means for implementing control of vehicle sequencing and subsystem configuration as commanded by the DCM or the flight crew. Included in the D&C are all displays and crew controls required for vehicle control and sequencing and for changing subsystem modes of operation. Routine and repetitive control tasks are automated to relieve the crew of menial tasks.

All measurements related to flight or system condition are displayed. Vehicle and mission situation information and computed potentials are presented in various selectable graphic formats on multiformat displays. Consumables data, time, navigation position information, computer operation monitoring parameters, and other update or urgent messages are presented by means of alpha-numeric panels. A caution and warning function employs a flexible logic capability to identify critical failures by related system and function.

The subsystem tree and a block diagram are provided in Figures 5-30 and 5-31 respectively.

Manual Controls

The primary manual flight controls consist of three-axis side-stick type rotation and translation controllers for attitude and translation; conventional pedal assemblies for rudder control; nosewheel steering and wheel brakes; and, a centrally mounted thrust control for the ABES.

Secondary controls are located at the crew station, include landing gear, parking brake, ABES deployment, flap control, etc. Manual controls also are provided for subsystem operation.

Integrated Controls

Multifunction (keyboard) type controls provide a crew interface with the DCM for flight control mode selection and manual inputting to the DCM computer.

Integrated Displays

The principal flight and subsystem displays are of the CRT type and provide a multiformat capability to support graphic displays of flight situation data, together with either analog or alpha-numeric presentation of subsystem status.

Other Displays

Digital time readouts are displayed to the crew. The units can accumulate GMT, GET, and up/down event time bases.

A caution and warning (C&W) function monitors the condition of the principal vehicle systems for anomolies which require crew action to avert compromise of safety or mission continuation. This function generates alarm signals for notification of the existence, criticality, nature, and location of anomolies in vehicle systems.

The C&W function monitors operating conditions by continuously comparing actual values of selected parameters to predetermined alarm limits. Crew display is effected by resettable master alarm lights and dedicated status indicators. Status memory and input inhibit functions also are provided.

5.8.2 Requirements

The displays and controls subsystem test requirements are noted in Table 5-23 and have been categorized by method of certification.

5.8.3 Approach and Rationale

The approach and rationale to be followed in development of the D&C is presented in the D&C Test Logic and Constraint Network, Figure 5-32. Examination of the network reveals that the development test program will follow two paths. The first will be human factors evaluation of the D&C and cockpit. Lighting levels, displays and controls arrangements, visibility, etc., will be evaluated early in the program to facilitate an optimum cockpit design. The other path will consist of the efforts required to mechanize the D&C. Details of the human factors evaluation effort are found in Volume II, Section 5.13 of this test plan.

The logic network shows that horizontal flight is constrained by qualification of Criticality I hardware and Vehicle 1 ground development tests. These tests will provide confidence that the D&C will control active subsystems (propulsion, power generation, etc.) and that this control capability will not be degraded by EMI or other undesirable interactions.

D&C hardware development will begin at the component level where new designs and repackaging of off-the-shelf display and control devices will be verified. This level of development will include CRT displays, alpha-numeric message panels, drive and selection electronics, keyboard, etc. Assembly level testing will be required only to verify panel packaging and component interfaces. As the D&C is comprised of many unrelated, non-interconnected elements, subsystem level testing is neither required nor feasible.

During the D&C development effort, other elements of the avionics are being developed. When the DCM and its software reach maturity, they will be interfaced in the ASIL with the D&C. Integration will consist of verification that the DCM and D&C can communicate.

After establishment of the D&C - DCM two-way communication capability, required D&C/DCM integration with the remaining avionics subsystems and simulations of certain nonavionics subsystems will be performed. Included in this category are those efforts necessary to develop and simulate the automatic landing functions.

D&C compatibility with its various applications will be verified by using particular D&C elements during the test of their interfacing subsystems. For example, an indicator dedicated to measuring ABES turbine RPM will be tested during the ABES testing.

During the in-process checkout phase, subsystem installation will be functionally verified to the extent necessary to detect and correct subsystem installation anomalies. Functional checkout will be performed on those portions of the subsystem that cannot be easily removed and replaced after the major subassemblies are mated. This checkout will be performed using on-board checkout equipment.

5.8.4 Test Article Requirements

A preliminary test schedule is provided in Figure 5-33. D&C subsystem test article requirements are summarized in Table 5-24. When feasible, subsystem elements will be reused for combined subsystems testing.

5.8.5 Support Requirements

Facility and support equipment requirements are identified in Table 5-25, and requirements include items necessary for subsystem level R&D testing and vehicle level in-process checkout.

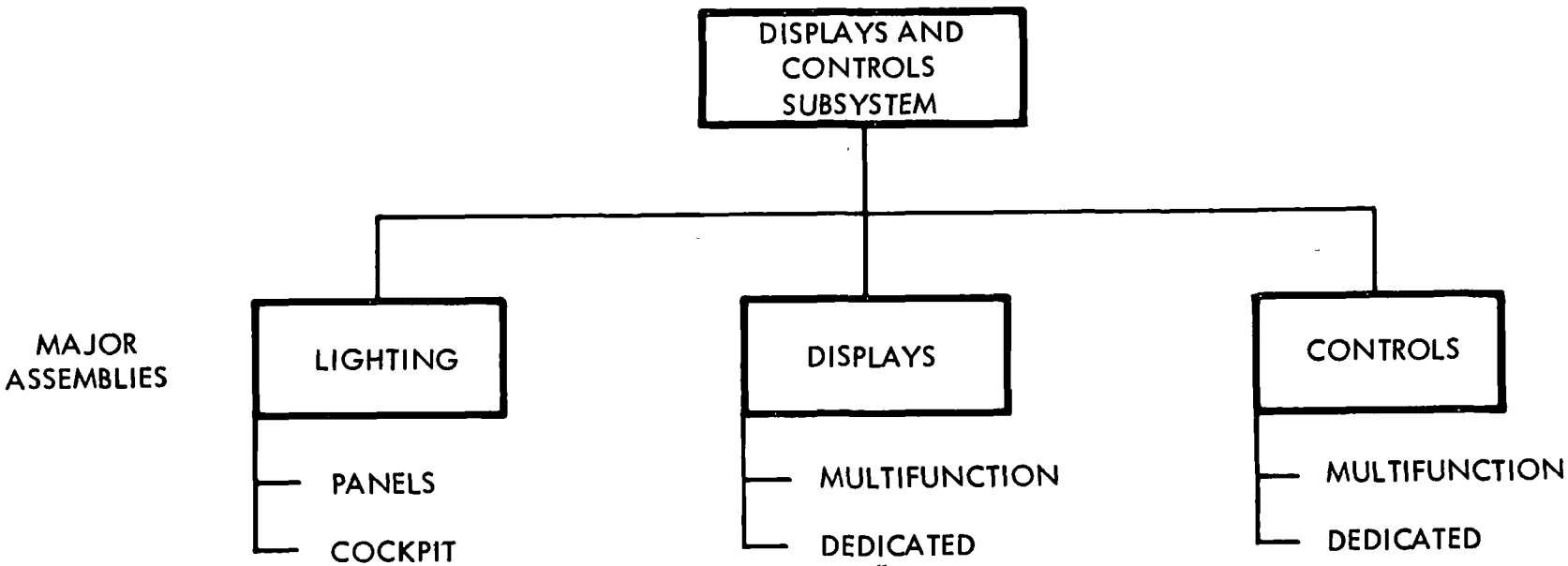


Figure 5-30. Displays and Controls Subsystem Elements

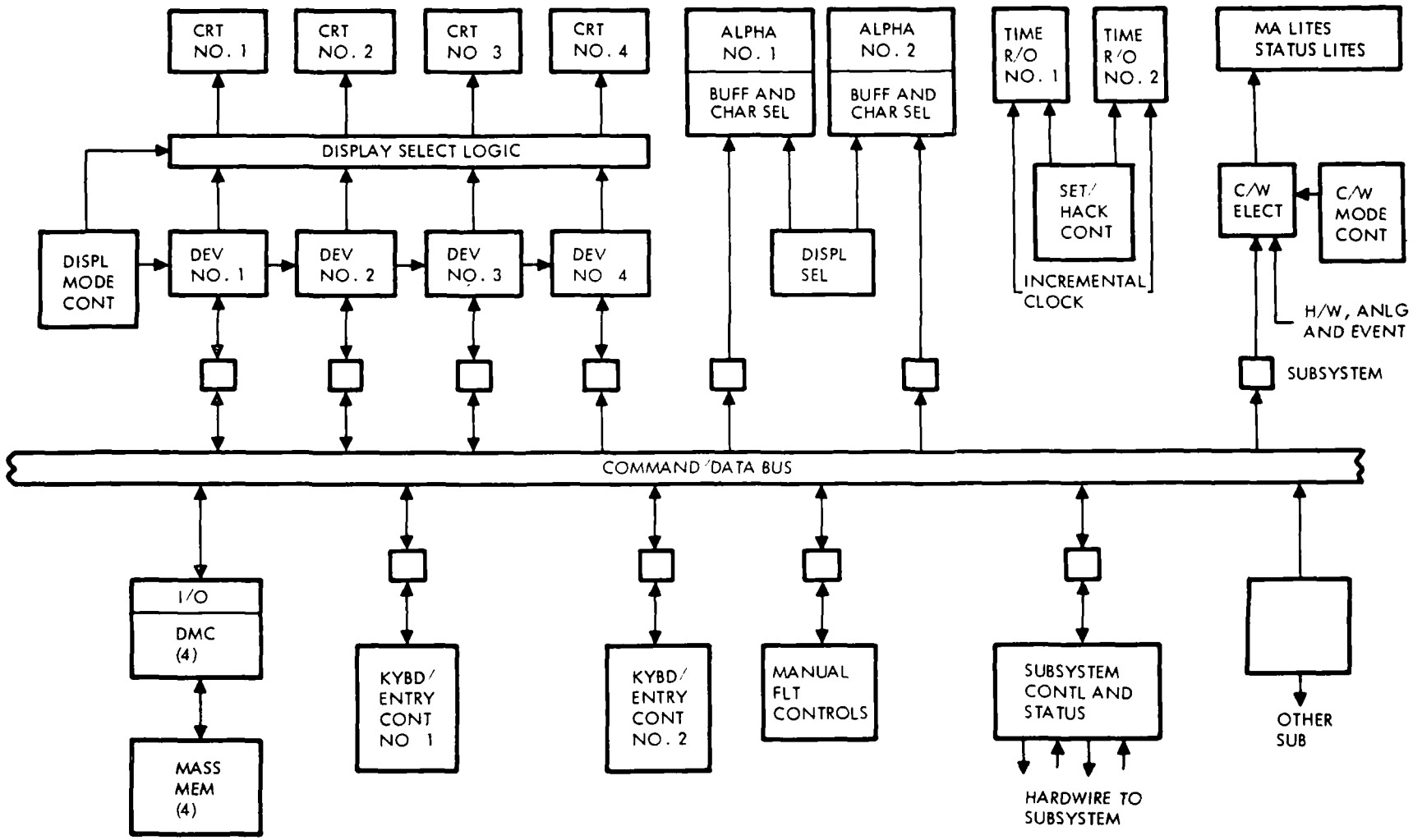


Figure 5-31. D&C Subsystem Schematic

Table 5-23. Displays and Controls Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
FUNCTIONAL REQUIREMENTS							
1. Ability to display data provided by DCM and C&W.						P	S
2. Ability to provide subsystem control via DCM or hardwire						P	S
3. Ability of the caution and warning function to identify critical failures and provide crew alert.						P	S
4. D&C functional operation/compatibility with all interfacing subsystems operating simultaneously.						P	S
5. Electromagnetic interference levels do not degrade the operation of the D&C.			S	S		S	P
6. Ability to satisfy all requirements during horizontal flight test.							P
7. Ability to satisfy all requirements during vertical flight test.							P
8. Adequacy of the safety lock and priority logic to prevent inadvertent initiation of hazardous functions.	S				S	P	
9. Compatibility of subsystem/vehicle SE interfaces						S	P
10. Ability of all D&C subsystem elements to operate within performance tolerances under environments specified.			S	S			P
DISPLAYS TEST REQUIREMENTS							
1. Ability of CRT's and associated drive and selection electronics to provide satisfactory displays.				S		P	S
2. Ability of alphanumeric displays, buffers, and selection electronics to provide satisfactory displays.				S		P	S
3. Ability of other selected display and control elements to perform their specified function (C&W, timing, keyboards, etc.).				S		P	S

Table 5-23. Displays and Controls Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
4. Ability of the alphanumeric message displays system elements to provide proper and adequate resolution.				S		P	S
5. Capability to provide predictive messages/displays in support of mission alternatives.						P	
6. Ability to display simulated non-avionics subsystems data received via DCM.						P	
7. Adequate alphanumeric displays rates						P	S
8. Information processing and presentation schemes for efficient crew utilization of information.				P		S	S
9. Adequacy of C&W upper and lower trip limits						P	S
CONTROLS TEST REQUIREMENTS							
1. Crew manipulation of controls results in proper response at crew compartment interface and associated subsystems.						S	P
2. Flight controls compatible with flight control system gains during all flight modes.		S				P	S
3. Ability to provide control, via DCM, of simulated non-avionics subsystems.						P	
4. Ability of crew over-ride system to alter flight modes and sequences.					S	P	S
5. All redundant units adequate to assure a safe return.	P	S			S	S	
6. Crew access to discrete control elements adequate.					S	P	S

Table 5-23. Displays and Controls Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
LIGHTING REQUIREMENTS							
1. Crew external visibility is not impaired by internal lighting configuration and cabin reflectances.				S	S		P
2. Adequacy of flight crew internal visibility.				S	S		P
3. Cabin/instrumentation illumination adequacy/compatibility under the varying contribution of external/extraneous illumination.					S		P
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Proper operation of display indicators. Controls produce proper signals at D&C panel interface.			P				
2. Caution and warning assemblies respond properly to simulated out-of-tolerance signals. Output signals are within specified parameters.			P				
3. Electrical circuit paths are per design, using automatic circuit analyzers.							P
4. Integrity of wire harness insulation.							P
5. Proper operation of indicators, lamps and CRT displays. Manipulation of controls results in proper response at crew compartment interface and associated subsystems.							P
6. Ability of DCM to control displays and respond to controls and controllers.							P

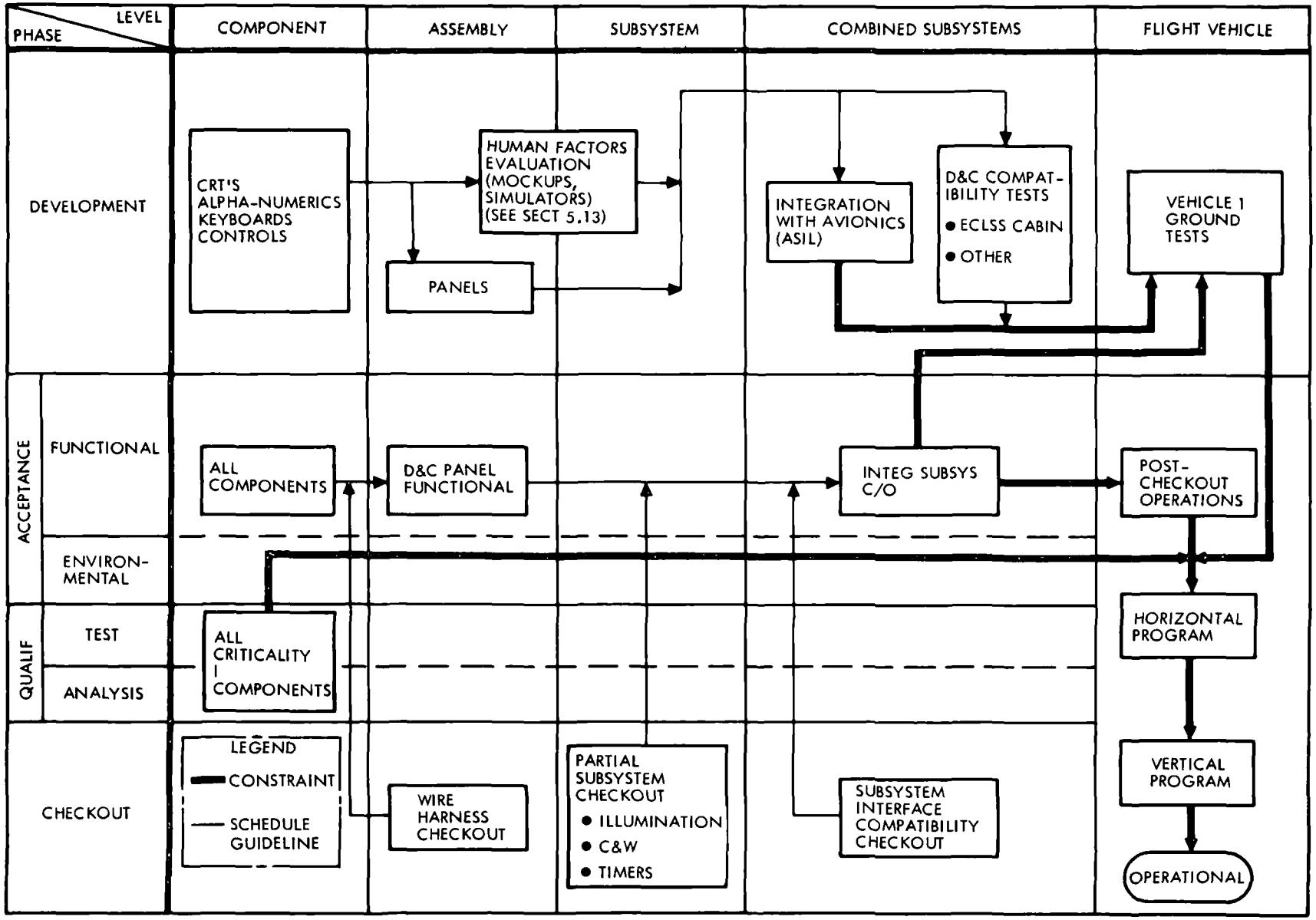


Figure 5-32. D&C Subsystem Test Logic and Constraint Network

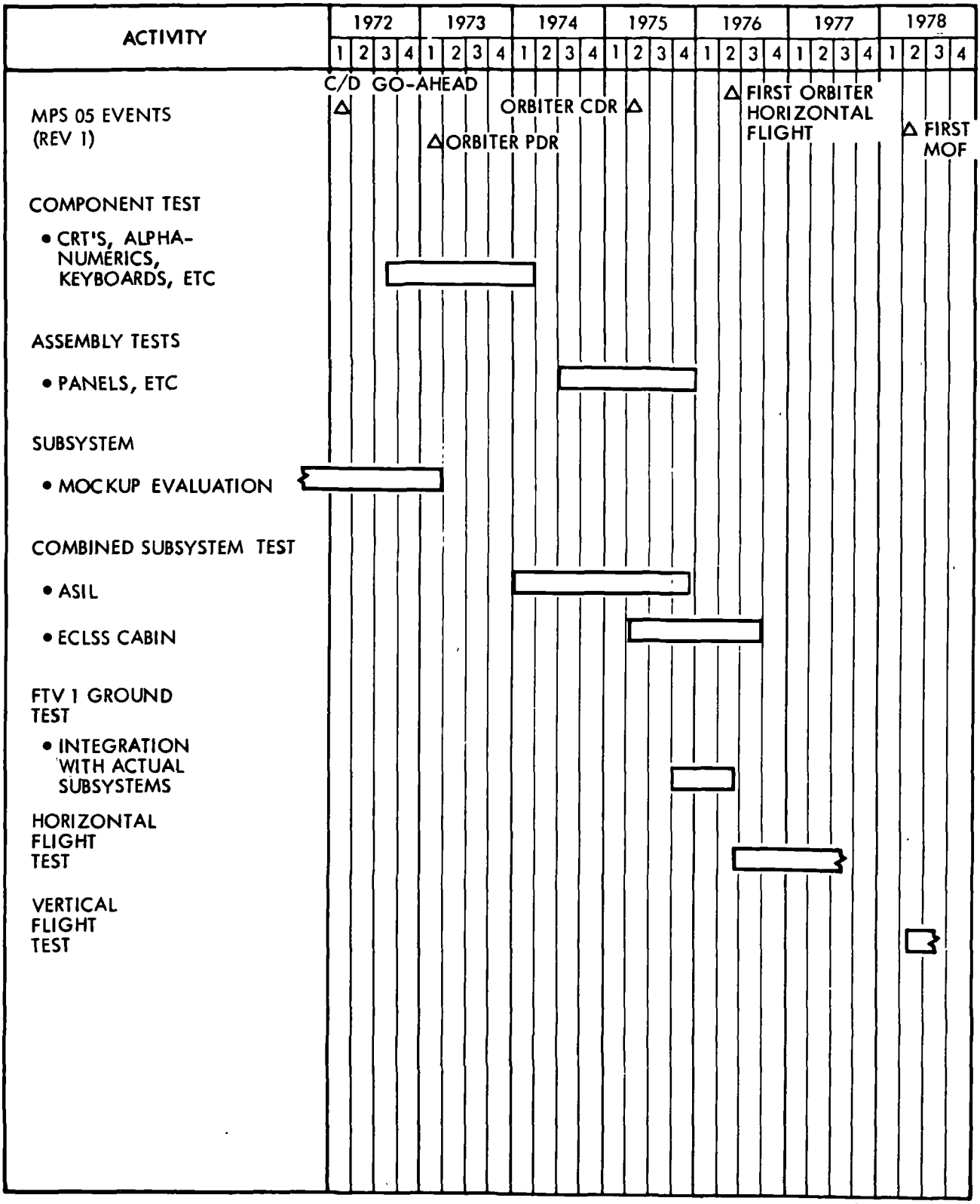


Figure 5-33. D&C Subsystem Test Schedule

Table 5-24. D&C Test Hardware Requirements

Assembly or Component	Quantity	
	D&C Testing	D&C Subsystems Compatibility Tests
Multifunction display CRT's and Associated drive and select LRU's	4	
Alpha-numeric display panels and associated drive and select LRU's	2	
Multifunction keyboard	2	
Caution and warning display and electronics	1	
Clock and associated electronics	1	
Manual flight controls	1 ship set	
D&C illumination	1 ship set	
Dedicated subsystem control and display elements		As required to support tests of each subsystem.

Note: The hardware quantities identified are for component and assembly testing, and do not include requirements for qualification or certification of individual components and assemblies. Contractor-utilized test hardware will be reused as required for ASIL combined subsystem testing.

Table 5-25. D&C Test Support Requirements

Area	Requirement
Facility	Capability to support environmental testing Electric power-120v 60 Hz three phase; 120v, 400 Hz three phase; 28 vdc. Air conditioning, heating. ventilation for mockups and test area
Support equipment	Assorted mockups for human factors evaluation (see Section 5.13). Stimuli generation equipment for multi-function displays Stimuli generation equipment for dedicated displays Miscellaneous environmental test equipment (including EMI) Vacuum cart Precision dc power supply Caution and warning checkout unit Binary to octal display Standard laboratory test equipment
Software	Programs to implement the following: Simulation of DCM interface Data acquisition and reduction to engineering units Test reporting

5.9 COMMUNICATION SUBSYSTEM

5.9.1 Description

The communications subsystem consists of dedicated assemblies and associated processing units. Figure 5-34 represents the integrated communications subsystem tree. Figure 5-35 illustrates the various elements of the subsystem. The subsystem elements are generally off-the-shelf units. The primary functions of the communication subsystem are as follows:

1. Provide voice intercom between crew members (a) passengers, (b) ground personnel, (c) space station, and (d) shuttle booster.

2. Provide two-way duplex voice communications and data between the orbiter and (a) MSFN stations, (b) relay satellite, (c) space station and (d) booster.

3. Provide two-way simplex communication between the orbiter and air traffic control stations.

4. Transmit and receive ranging signals from (a) ground transponders and (b) space station. Receive and retransmit ranging signals to MSFN.

5. Provide capability to obtain angle and range tracking measurements between orbiter and a passive uncooperative target on special missions (payload function).

6. Provide identification signals to navigational and air traffic control stations.

7. Provide landing aids equipment capable of supporting the automatic landing function.

8. Provide crash-type data and voice recording capability and radio beacon capability which have a high probability of surviving atmospheric emergency conditions.

Intercommunications between the orbiter personnel is provided by a conventional earphone/microphone system. In addition, communications with the booster is provided through the interstage umbilical, which is severed immediately prior to vehicle separation.

The audio center equipment accomplishes the necessary audio signal amplification, switching, and routing to the audio bus, transmitters, and flight log recorder for transmission, reception, and storage of voice.

A conventional ATC transponder system is provided for orbiter identification and altitude information to FAA Traffic Control Centers.

To provide information in the event of a nonroutine flight, a flight log recorder and a recovery beacon are installed in the vertical stabilizer.

Rendezvous, navigation, state vector update, and landing are augmented by a precision ranging transceiver in conjunction with ground based transponders and a space station transponder. The transceiver derives raw range and range rate information from Doppler principles and phase comparisons of transmitted and received signals. The DCM performs the necessary calculations on the raw ranging data. A radar altimeter also aids the landing function.

A unified S-band capability provides two-way duplex voice and data and provides turnaround of ranging signals.

Simplex two-way voice communications with air traffic control is provided via UHF.

Duplex voice and data between orbiter and a satellite relay system is provided via VHF/FM.

5.9.2 Requirements

The communication subsystem test requirements are delineated in Table 5-26 and are categorized by method of certification.

5.9.3 Approach and Rationale

The approach and rationale to be used in development of the communication subsystem are presented in the test logic and constraint network, Figure 5-36. Horizontal flight is constrained by qualification of Criticality I hardware and FTV 1 ground tests of the antenna system. These antenna checks will be the first full-scale evaluation of the antenna system since previous testing has been accomplished on scale models or, in the case of FTV 1, in the confines of the assembly building. EMC/EMI will also be a key objective during the FTV 1 ground tests.

Selected elements of the subsystem will undergo thermal vacuum testing at the component, subassembly, and/or assembly level. Subsystem and combined subsystem level ground-thermal-vacuum testing is not presently

planned. Overall orbiter thermal-control test requirements are summarized in Section 6.6. Communication subsystem development will initially be component development of reusable antennas and non-off-the-shelf equipment as identified in Figure 5-36. Development of antenna arrangements in the mated and unmated configuration will also be in process on scale models. The subsequent test effort will be to integrate the communications subsystem elements into a functional subsystem. At this level, the ability of the many components to interface properly will be verified.

Avionics combined subsystems testing will verify the ability of the communications subsystem to adequately perform while interfaced with the D&C, the DCM, and its software. The ability of the communication subsystem to successfully obtain, process, and transmit data will also be verified. The final integration task will be verification that the communication subsystem functions are able to support automatic vehicle landing requirements. A portion of the communication audio system will be utilized during ECLSS combined subsystem testing and will afford an opportunity for crew evaluation of the orbiter audio capability.

The in-process phase of acceptance checkout of the communication subsystem will consist of voltage standing wave ratio measurements of installed coaxial cables and antennas. Electromagnetic compatibility checks will also be performed. The subsystem installation will be functionally verified to the extent necessary to detect and correct subsystem installation anomalies. Functional checkout will be performed on those subsystems which cannot be easily accessed after mate with other major vehicle subassemblies. This will be performed with a DCM synthesizer and data monitoring consoles.

A preliminary test schedule is presented in Figure 5-37.

5.9.4 Test Article Requirements

Table 5-27 delineates test hardware which will be used for subsystem level R&D testing and, when feasible, reused for combined subsystem testing.

5.9.5 Support Requirements

Table 5-28 delineates the support requirements for subsystem level R&D testing and vehicle level in-process checkout.

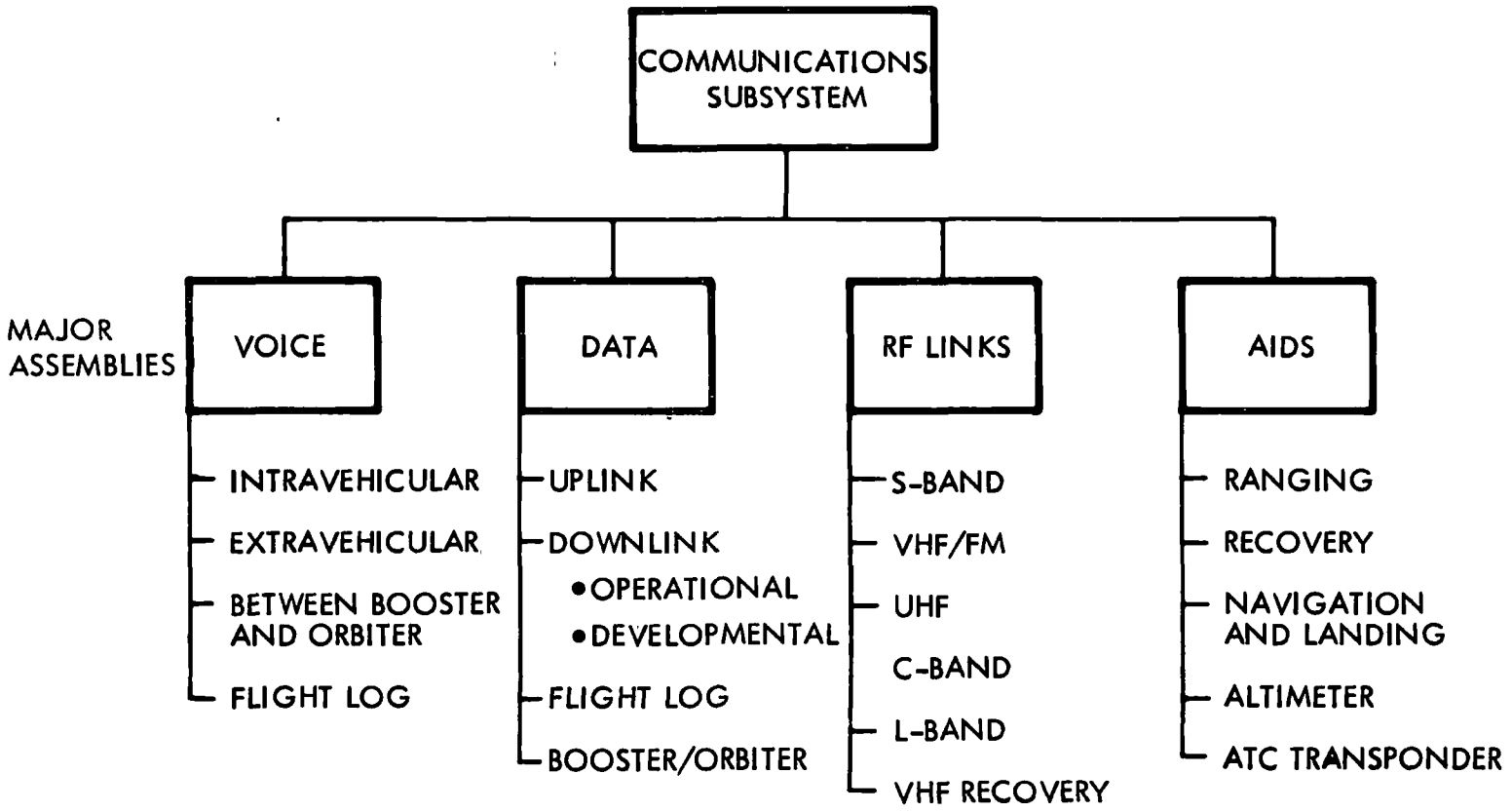


Figure 5-34. Communications Subsystem Elements

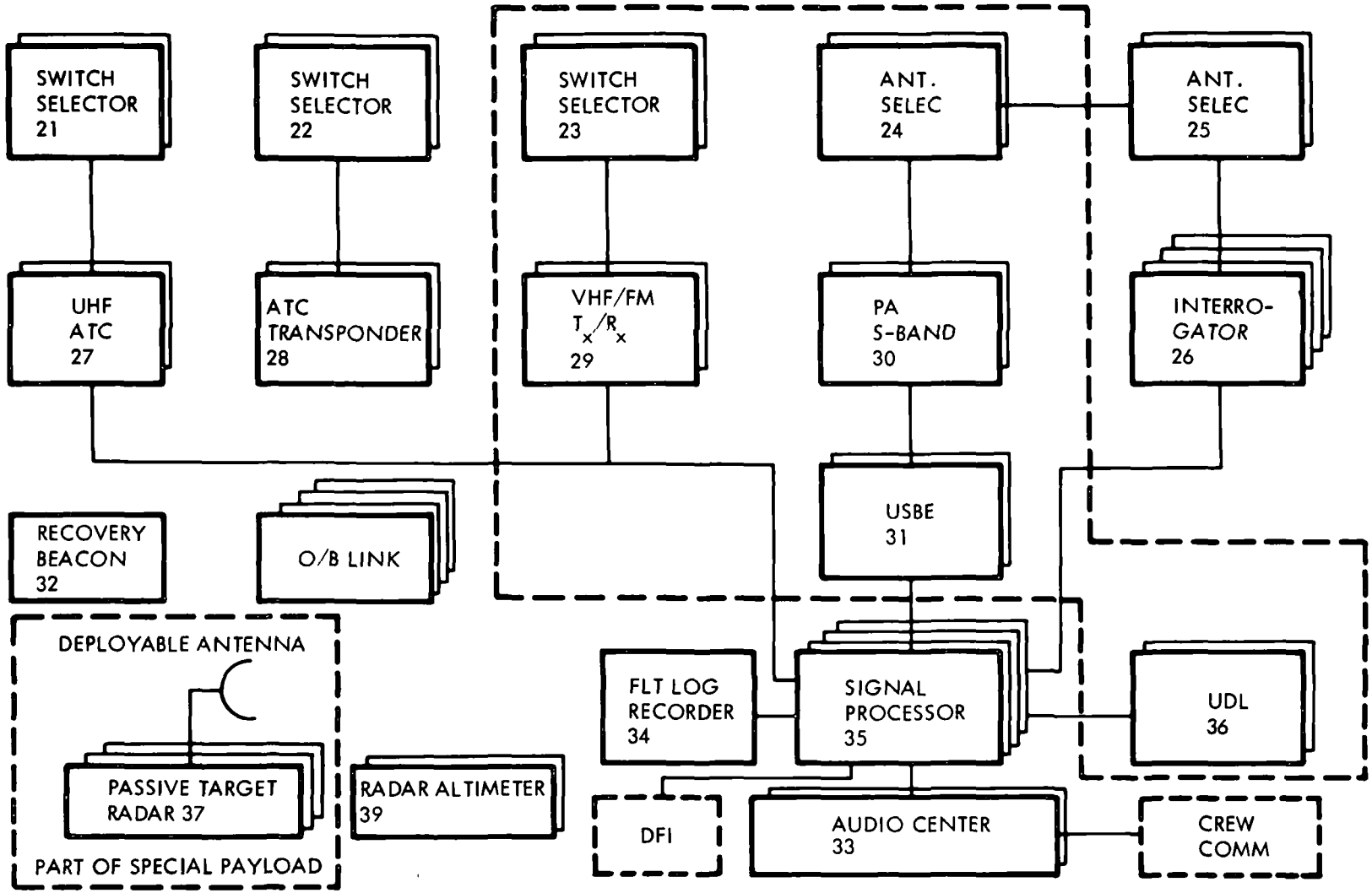


Figure 5-35. Communications Subsystem Schematic

Table 5-26. Communication Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
OPERATIONAL REQUIREMENTS							
1. Compatibility with existing ground radio services to maximize frequency spectrum sharing and minimizing mutual interference.	S				S		P
2. Satisfactory communication subsystem redundancy management and functional capability while under control of the DCM, COFI, and D&C.						P	S
3. Evaluation of subsystem susceptability to EMI and monitor EMI generation.				S		P	S
4. Overall ability of communication to meet operational requirements during horizontal flight test.							P
5. Overall ability of communication to meet operational requirements during vertical flight test.							P
6. Ability to service booster/orbiter umbilical in the horizontal and vertical attitudes.							P
7. Ability of all communication subsystem elements to operate within performance tolerances under environments specified.			S	S			P
NAVIGATION AIDS REQUIREMENTS							
1. Radar altimeter performance and passive target radar interface capability.					P		S
2. Satisfactory performance of UHF recovery beacon.					S		P
3. Capability of communication subsystem to respond to ATC interrogation.	S				S		P
4. Capability of communication subsystem to properly interrogate simulated ground transponders in support of precision ranging state vector update.	S				S		P

Table 5-26. Communication Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
5. Capability of the communication subsystem in conjunction with the DCM to provide navigation updates via precision ranging.	S	S			S		P
6. Communication subsystem interface with the automatic landing functions.	S	S			S	S	P
RF SYSTEMS REQUIREMENTS							
1. Adequate antenna radiation coverage by antennas for all RF links in the mated and unmated configurations on an antenna range.		P					
2. Antenna systems compatibility with applicable transmitters and/or receivers.		P					S
3. Proper transceiver operation under hot and cold (low, high) power.				S	P		
4. Proper operation of all antenna selectors as programmed by the DCM.						P	S
5. Signal processors provide the proper interface between the airborne data gathering equipment and RF electronics accomplishes proper signal modulation.					P	S	
6. Proper installed antenna power outputs to verify the compatibility of the effective radiated power with the data bit rate modulation efficiency and heat dissipation.							P
7. Proper operation of all antenna systems in the space shuttle mission thermal environment.			P				S
8. All RF systems shall operate in mission environment without voltage breakdown (corona).			P				S
9. RF systems insertion losses within acceptable limits.				S	S		P

Table 5-26. Communication Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
10. Adequacy of antenna/s gain/directivity, power output and crosstalk isolation between antenna systems.	S		S				P
11. Adequacy of the antenna selection manual override capability.						S	P
12. Communication elements do not radiate or absorb radiation from other RF sources.			S	S	S		P
13. Proper loading of antennas and receiver reception of transmitted signal.			S	S	S		P
AUDIO SYSTEMS REQUIREMENTS							
1. Two-way simplex voice with ATC via UHF.					S		P
2. Satisfactory orbiter crew member intercommunications.					S		P
3. Proper recording of voice by the flight log recorder.				S	P		
4. Audio center voice signal amplification, switching, and routing to the audio bus and via the signal processor to the UHF, VHF and S-band transceivers.				S	P		
5. Proper signal processor operation in signal modulation, demodulation, mixing, routing, and switching.				S	P		
6. Satisfactory audio intercommunications through the interstage umbilical.					S		P
DATA SYSTEMS REQUIREMENTS							
1. Development flight instrumentation data handling capability.					S		P
2. Ability of communication subsystem to acquire, process, and communicate data from all avionics and nonavionics subsystems.					S	S	P

Table 5-26. Communication Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
3. Ability of the flight log recorder to record required parameters.				S	P		
4. Capability of the communication subsystem to properly process, transmit, and receive actual and simulated flight information.					P	S	S
5. Capability to transfer selected data between orbiter and booster.					S		P
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Measurement of VSWR in communications transmitter, receivers, and transponder coaxial cables by using standard lab equipment.							P
2. VSWR measurement of antennas with their coaxial cables							P
3. Communication coaxial cables do not radiate or absorb radiation from other RF sources.							P
4. Proper transmitter loading of antennas. Verify receiver reception of transmitted signal.							P
5. Communications integration with DCM; demonstrate ability of DCM system to control and monitor communications systems.							P
6. Communication black boxes do not radiate or absorb radiation from other RF sources.							P

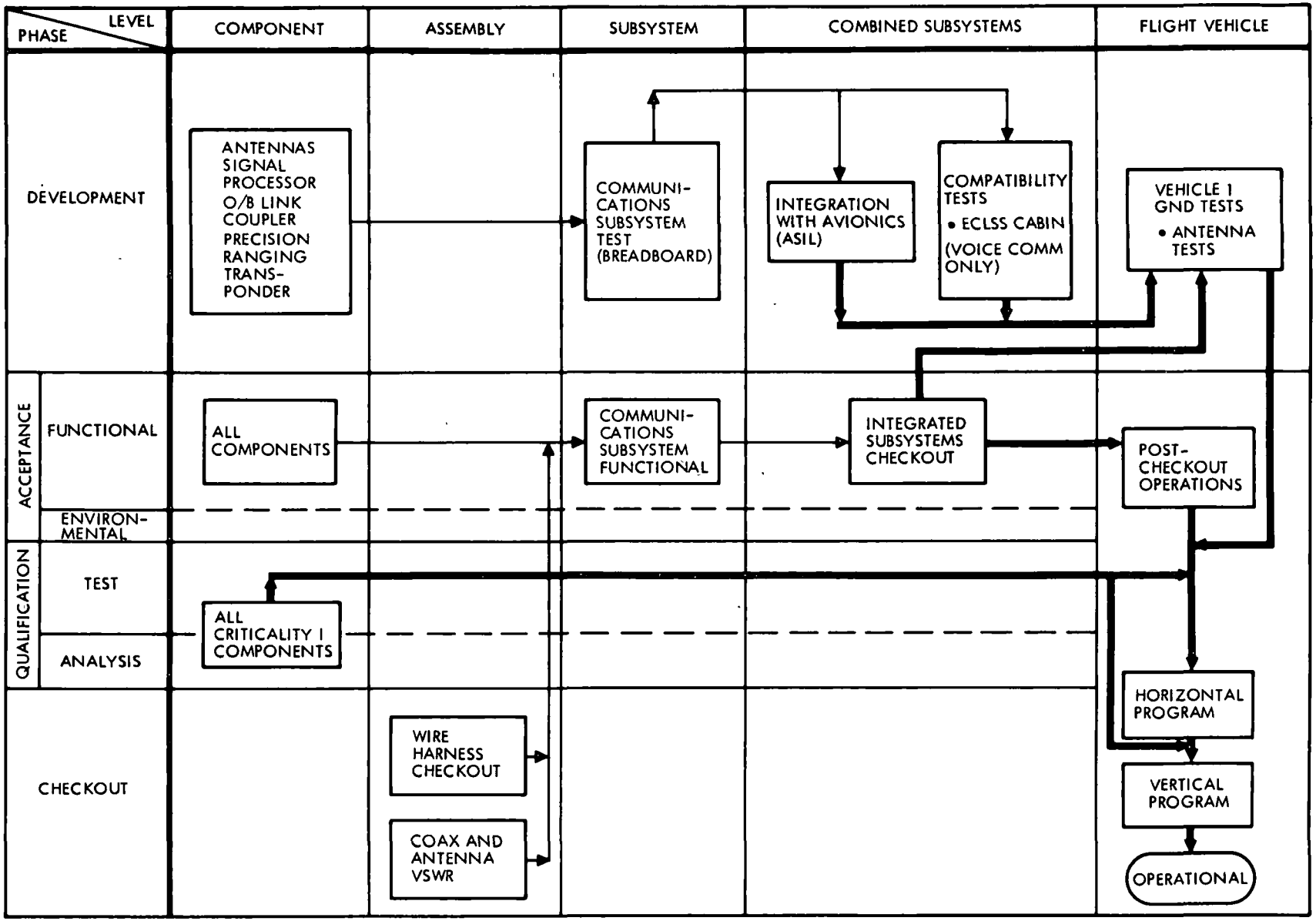


Figure 5-36. Communications Subsystem Test Logic and Constraint Network

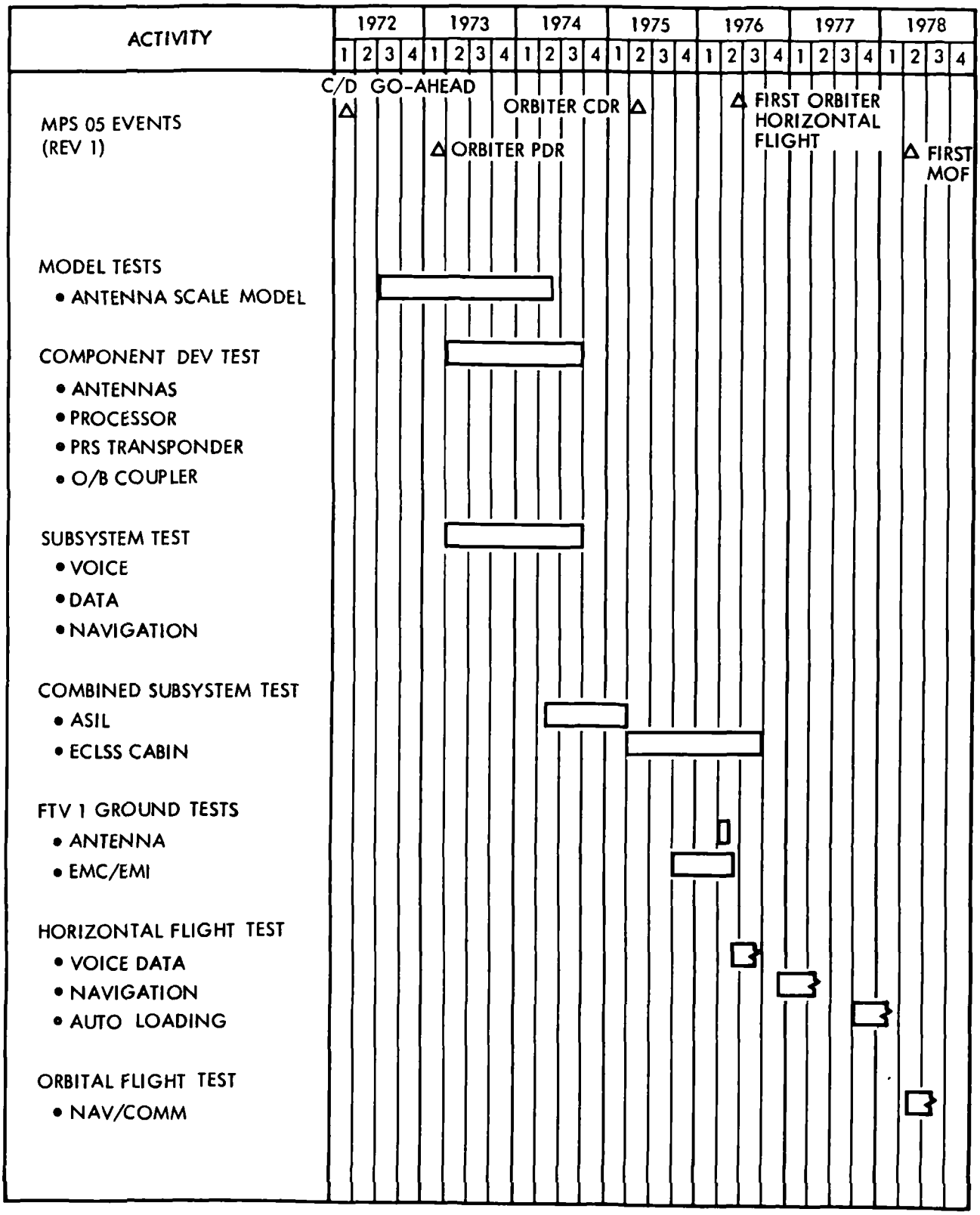


Figure 5-37. Communications Subsystem Test Schedule

Table 5-27. Communication Subsystem Test Hardware Requirements

Component or assembly	Quantity	
	Subsystem Testing	Antenna Scale Model Testing
S-band power amplifier	1	
Unified S-band equipment	1	
flight log recorder	1	
Signal processor	4	
Precision ranging	4	
Audio center	2	
Radar altimeter	2	
VHF recovery beacon	1	
ATC transponder	2	
ATC voice transceiver	2	
Orbiter/booster link and decoder	2	
Antenna selectors	5	
Passive target radar	1	
Crew head sets	100 percent	
VHF/FM	2	
Orbiter model (includes scaled antennas)		1
Mated orbiter/booster model (includes scaled antennas)		1
Updata link	1	

Note: The hardware quantities identified are for subsystem level testing, and do not include requirements for development/qualification of individual components and subassemblies. Contractor-utilized subsystem test hardware will be reused during ASIC combined subsystem testing.

Table 5-28. Communication Subsystem Test Support Requirements

Area	Requirement
Facility	Electrical power 120/208 v three phase 60 hertz 120/208 v three phase 400 hertz 28 vdc regulated Capability to support environmental test Air conditioning/heating/ventilation Scale model antenna range
Support equipment	Subsystem test control panel/console RF and telemetry ground station Stimuli equipment for radars, transponders and ranging equipment Simulated voice and data sources Cooling and circulation unit (for coldplate network) Miscellaneous environmental test equipment (Including EMI) Elect ground power and distribution Auto circuit analyzer Elect cable set VSWR measurement unit RF checkout equipment
Software	Programs to implement following Control of test sequence Simulation of DCM and D&C Data acquisition and reduction to engr units Test reporting

5.10 ELECTRICAL POWER DISTRIBUTION AND CONTROL (EPD&C) SUBSYSTEM

5.10.1 Description

The orbiter EPD&C subsystem consists of a collection of elements which satisfies the requirements for electrical power control, power conversion, power distribution and lighting. The EPD&C tree is shown in Figure 5-38; Figure 5-39 is a schematic of the subsystem.

Electrical power control, under normal conditions, is achieved via conventional switches, contactor/relays, circuit breakers and remotely controlled solid state or electromechanical switches. Control of power to faulted loads and buses is primarily handled by incorporating automatic fault sensing and trip capability into the various solid state and electromechanical power controllers, but circuit breakers and fuses are also used.

The orbiter power conversion capability consists of transformer-rectifiers which convert 115-volt 3-phase 400-Hz main ac bus power into 28-volt dc power for the main dc bus, inverters which convert 28 volt dc main dc bus power into 115-volt 400-Hz 3-phase power for the inverter ac bus, and a battery charger which converts 28 volt dc power into dc power suitable for secondary battery charging.

Orbiter distribution of power derived from APU's, space station, or ground power is achieved by a redundantly structured 115 volt, 3-phase, 400 Hz bus which is known as the main ac bus. Distribution of fuel cell power and rectified power from the main ac bus is handled by a redundantly-structured 28 volt dc bus. Distribution of 115-volt 3-phase 400-Hz power from the ac inverters is accomplished via the inverter ac bus. This bus powers loads requiring ac power when the main ac bus is dormant. Redundant, battery-powered sequencer buses will provide power to the pyrotechnic loads and limited power to the main dc buses during mission contingencies.

Orbiter lighting requirements are implemented by incandescent, fluorescent, and gaseous discharge devices. Flourescent and incandescent devices will provide lighting of the flight deck, the aft flight deck, and airlock areas, control and display illuminations, exterior running lights, docking lights, position and fuselage lights and landing and taxi lights. A white, flashing light will augment rendezvous.

5.10.2 Requirements

The EPD&C subsystem test requirements listed in Table 5-29, have been categorized by method of certification.

5.10.3 Approach and Rationale

The approach and rationale to be followed in the development of the EPD&C subsystem is presented in the test logic and constraint networks (Figure 5-40).

Examination of the network reveals that horizontal flight is constrained by qualification of Criticality 1 components and assemblies and ground development tests of flight test vehicle 1. These ground development tests will provide the first actual mating of the airborne power sources, power distribution system, controls and loads. Selected elements of the subsystem will undergo thermal vacuum testing at the component, subassembly, and/or assembly level. Subsystem and combined subsystem level ground-thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6.

Of interest is the use of the EPD&C breadboard for subsystem development as well as ASIL support and integration. This will be carried out as follows. Upon completion of EPD&C testing on the breadboard with simulated loads, synthetic controls and APU generators driven by facility prime movers, the EPD&C breadboard will be interconnected with the relatively small portion of the EPD&C needed to support the avionics subsystems. This approach was selected because a key test objective is verification that EPD&C power quality is compatible with the avionics loads.

During the in-process checkout phase, subsystem installations will be functionally verified to the extent necessary to detect and correct subsystem installation anomalies. Functional checkout will verify that ac and dc power controls, both manual and automatic, are capable of controlling current and voltage to electrical loads. The checkout will include application of power to buses and verify ability to transfer electrical power load to alternate buses and verify power distribution from source to individual circuit breakers. Figure 5-41 shows the preliminary test schedule.

5.10.4 Test Article Requirements

Table 5-30 delineates test hardware which will be used for subsystem level R&D testing and will also be used in support of combined subsystem testing.

5.10.5 Support Requirements

Support requirements for EPD&C subsystem level R&D testing and in-process checkout are identified in Table 5-31.

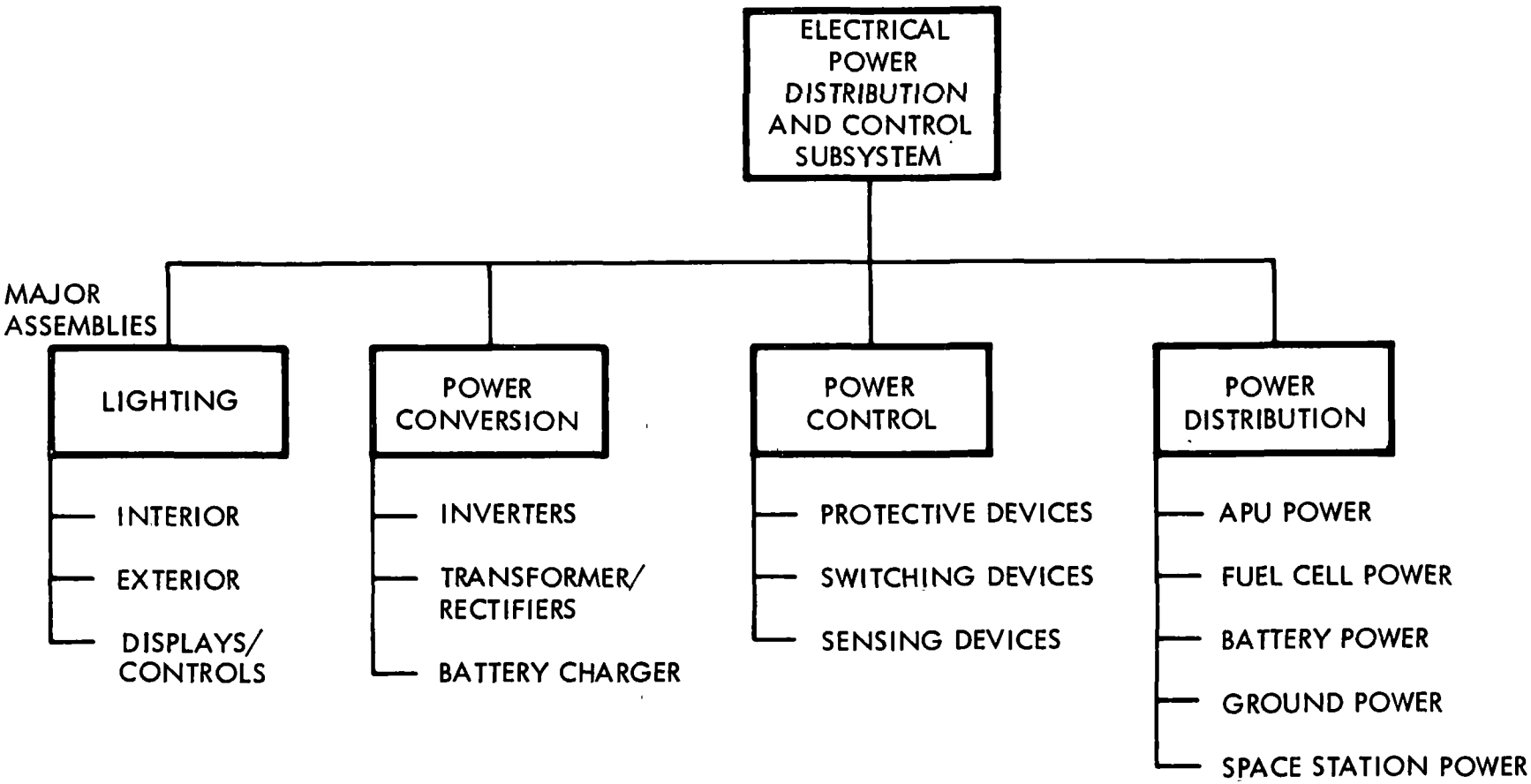


Figure 5-38. Electrical Power Distribution and Control Subsystem Elements

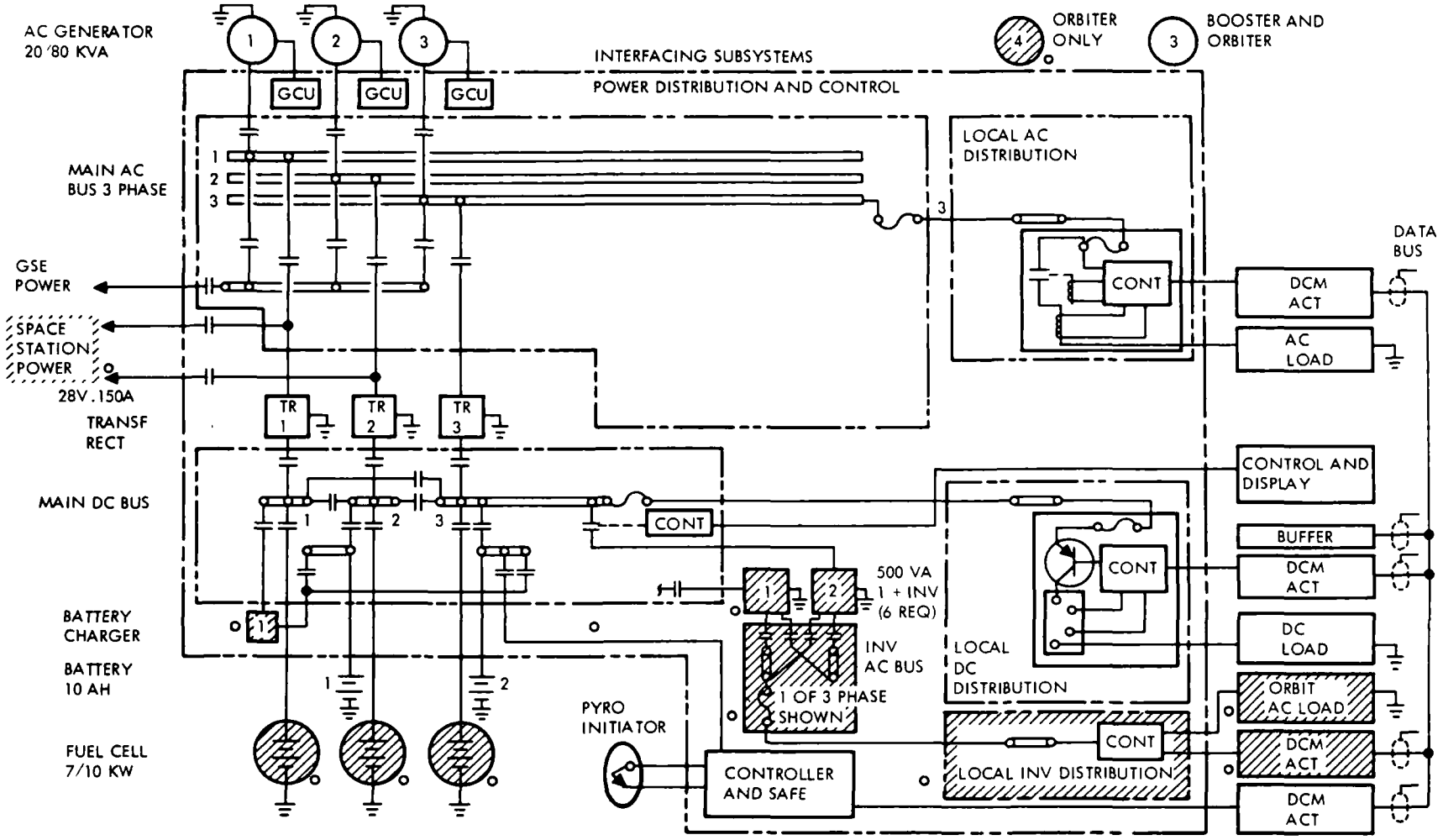


Figure 5-39. Orbiter Baseline Electrical Power Distribution and Control Subsystem Schematic

Table 5-29. Electrical Power Distribution and Control Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
OPERATIONAL REQUIREMENTS							
1. The EPD&C can supply electrical power with specified characteristics to all loads from airborne, ground and space station sources (simulated).					S	P	S
2. The EPD&C can meet all power delivery, switching, and redundancy requirements while under control of the DCM, COFI and D&C.					S	P	
3. Performance (stability) of the EPD&C during simulated or actual switching of key loads.					S	S	P
4. Ability of the EPD&C to furnish all vehicle loads with specified power, while supplied with active APU and fuel cell power.							P
5. Overall ability of EPD&C to meet operational requirements during horizontal flight test.							P
6. Overall ability of EPD&C to meet operational requirements during vertical flight test.							P
7. Accessibility of components in mated and horizontal modes.	S						P
8. Ability of EPD&C subsystem to operate in redundancy modes.						P	S
9. Capability and procedures for transfer from ground to airborne sources and vise-versa.							P
10. Ability to engage and disengage all EPD&C umbilicals.							P
11. Ability to safe/arm all ordance circuits.					P		
12. Ability of all EPD&C subsystem elements to operate within performance tolerances while under environments specified.			S	S			P

Table 5-29. Electrical Power Distribution and Control Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
SUBSYSTEM REQUIREMENTS							
1. Protective devices adequately protect power sources, buses, and wiring and are properly sized for their respective loads.	S				P		
2. Satisfactory EPD&C recharging of secondary batteries.					P		
3. Satisfactory ac inverter synchronization.					P		
IN-PROCESS CHECKOUT REQUIREMENTS							
1 Wire harness has proper insulation resistance				S			P
2. Wire harness continuity per engineering documentation.				S			P
3. Ac and dc bus isolation and electrical ground points.							P
4. Functional test of control assemblies at the component level.				P			
5. Functional test of installed EPD&C							P

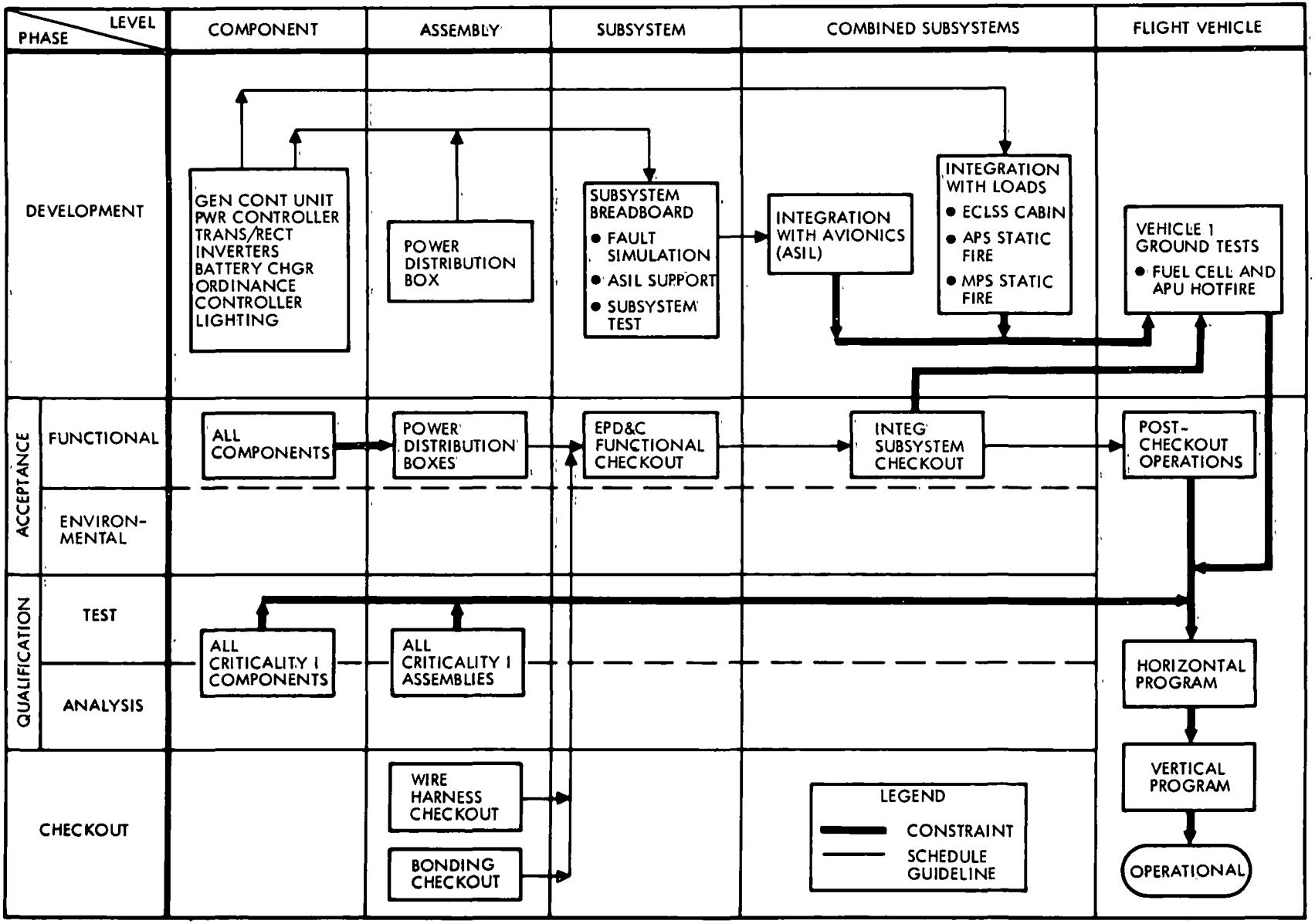


Figure 5-40. EPD&C Test Logic and Constraint Network

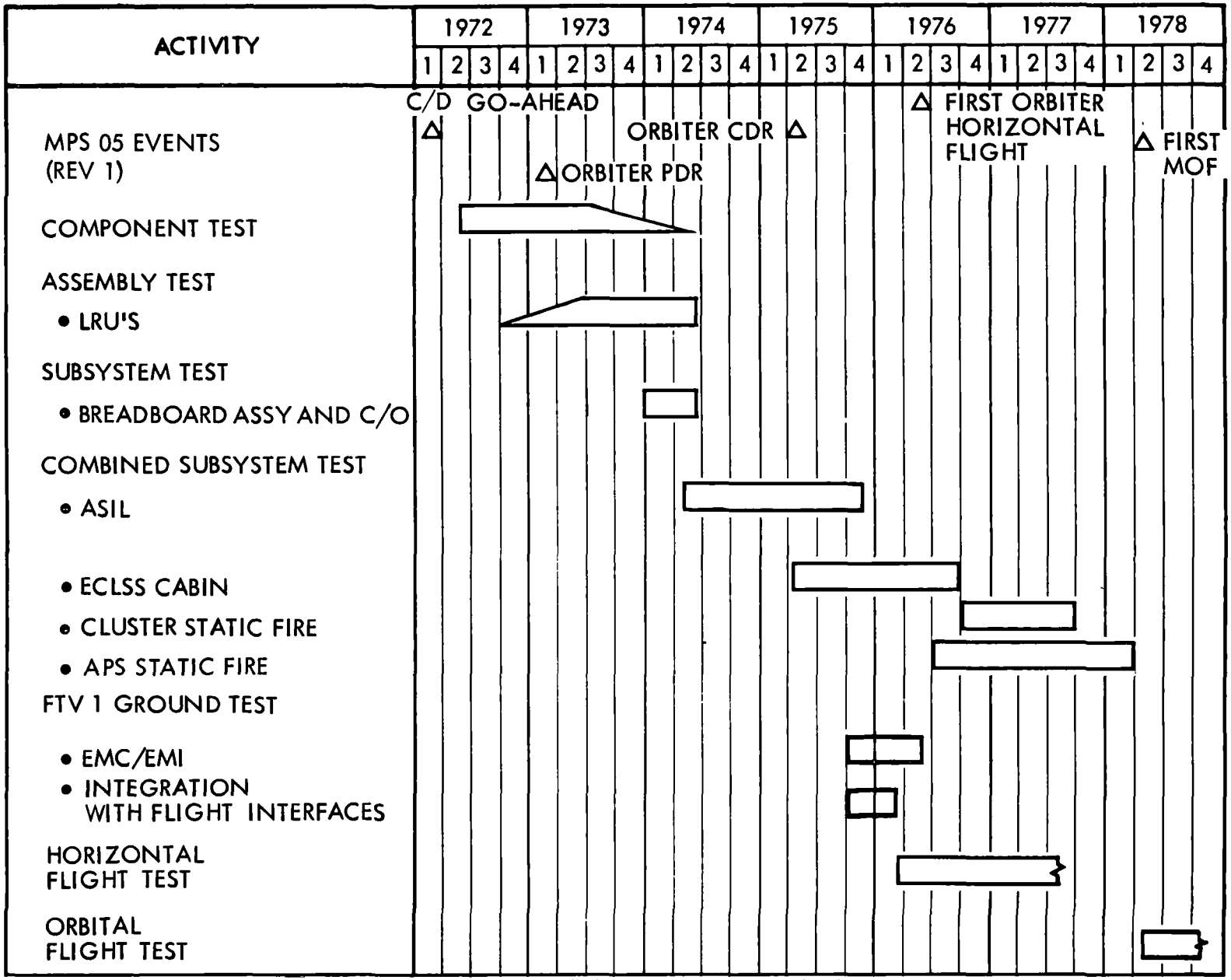


Figure 5-41. EPD&C Subsystem Test Schedule

Table 5-30. EPD&C Subsystem Test Hardware Requirements

Assembly	Quantity for Subsystem Testing
Transformer/rectifier	3
Inverter	6
Electromechanical power controllers	10 percent
Solid state power controllers	75 percent
Hybrid power controllers	75 percent
Generator control unit	3
Battery charger	1
Power distribution boxes	100 percent
*Power generation	
Generator (APU)	3
Battery	2
Ordinance controller	1
*Items not part of EPD&C subsystem.	

Notes: The hardware quantities identified are for subsystem level testing, and do not include requirements for development/qualification of individual components and subassemblies. Contractor-utilized test hardware will be reused as required for ASIL combined subsystems testing.

Table 5-31. EPD&C Subsystem Test Support Requirements

Area	Requirement
Facility	Electrical power 120 v one phase 60 Hertz 120/208 v three phase 400 Hertz Power for APU generator prime movers 28 vdc Capability to support environmental test Air conditioning/heating/ventilation
Support equipment	Prime movers (3) for driving APU generators Load banks Fault simulations and necessary controls Simulated fuel cell power Subsystem test control panel (substitutes for (DCM/D&C) Miscellaneous environmental test equipment (Including EMI) Cooling and circulation unit (if liquid cooling required) Standard laboratory test equipment Electrical ground power and distribution Automatic circuit analyzer Elect cable set Caution and warning checkout unit Bus monitoring recorder Bus monitoring unit
Software	None (see ASIL section 6.2)

5.11 INSTRUMENTATION SUBSYSTEM

5.11.1 Description

The orbiter instrumentation subsystem consists of development flight instrumentation (DFI) and operational vehicle instrumentation. Figure 5-42 shows the subsystem tree; Figure 5-43 is a DFI block diagram.

The DFI provides the means for collecting, multiplexing, recording and relaying flight test data to the ground and consists of multiple data acquisition units, each collecting data from typically 256 transducer/conditioners, multiplexing the collected data and inputting the data, via the DFI data bus, to the DFI format controller. The DFI format controller interleaves the multiplexed data for recording and/or transmission to the ground via S-band telemetry or umbilical. Measurements requiring high resolution (such as vibration) will be implemented through a limited number of FM/FM channels. The majority of the DFI will be removed upon completion of flight test.

Operational instrumentation requirements will be satisfied jointly by the subsystem requiring the instrumentation and the data and control management (DCM) subsystem. The transducer, wiring, and signal conditioner will generally be part of the subsystem they service while collection, multiplexing, distribution, and recording of the data generated will be performed by the DCM. The communications subsystem will provide the instrumentation data link with the ground.

5.11.2 Requirements

The instrumentation subsystem test requirements are listed in Table 5-32 and the levels of verification are identified.

5.11.3 Approach and Rationale

The approach and rationale to be used in the development of the instrumentation subsystem are presented in the test logic and constraint network (Figure 5-44). Examination of the network reveals that testing will be accomplished initially at the component and black box level, presumably by subcontractors. Breadboarding of new circuit and modification of off-the-shelf equipment will precede finalization of the design. Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, and/or assembly level. Subsystem and combined subsystem level ground-thermal-vacuum testing is not presently planned. Overall orbiter thermal-control test requirements are summarized in Section 6.6.

Production versions of the black boxes will be certified to assure proper performance under worst-case environments.

Test effort required to develop transducers, or to certify them for a new environment, will also be the responsibility of subcontractors as the instrumentation requirements are finalized. See Figure 5-45.

DFI

As the DFI elements (black boxes) become available to the orbiter contractor, they will be interfaced and integrated. Next the DFI subsystem, with simulated data inputs, will be integrated with its communications, DCM, and EPD&C interfaces in the ASIL.

Operational Instrumentation

The operational instrumentation is a fragmented subsystem in which the DCM ties the fragments together. Testing will therefore consist of transducer/conditioner development and integration with the DCM in the ASIL and on flight test vehicle 1.

To achieve early validation of both DFI and operational transducer and conditioner applications, flight-type instruments will be incorporated into test articles related to other orbiter subsystems (structural test articles, static firing stands, etc.).

In-process acceptance checkout will begin with an acceptance test at the subcontractor facilities where the transducers, conditioners, and black boxes are fabricated. Following installation in the orbiter sections, a check to verify the installation will be performed. The final check will be an end-to-end check of each measurement. Generally, the ambient reading for each measurement will be verified against the known ambient. Then, stimuli (heat, cold, etc.) will be applied to each transducer, when feasible, to verify measurement polarity and functional status.

Preflight runup of previously dormant subsystems (ABES, APU's, etc.) will provide dynamic end-to-end instrumentation checks.

5.11.4 Test Article Requirements

Table 5-33 delineates test hardware which will be used for subsystem level R&D testing and, when feasible, reused for combined subsystem testing.

5.11.5 Support Requirements

Table 5-34 delineates the support requirements for subsystem level R&D testing and vehicle level in-process checkout.

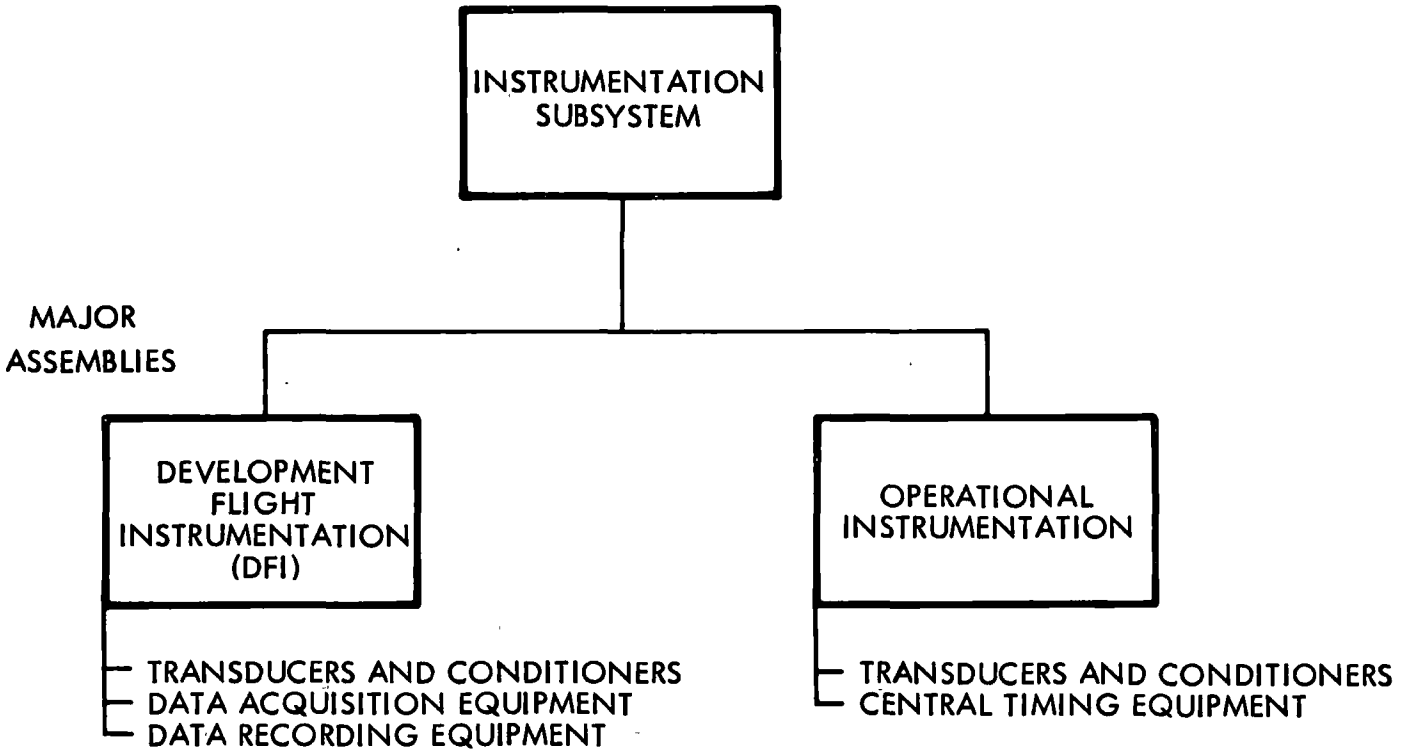


Figure 5-42. Instrumentation Subsystem Elements

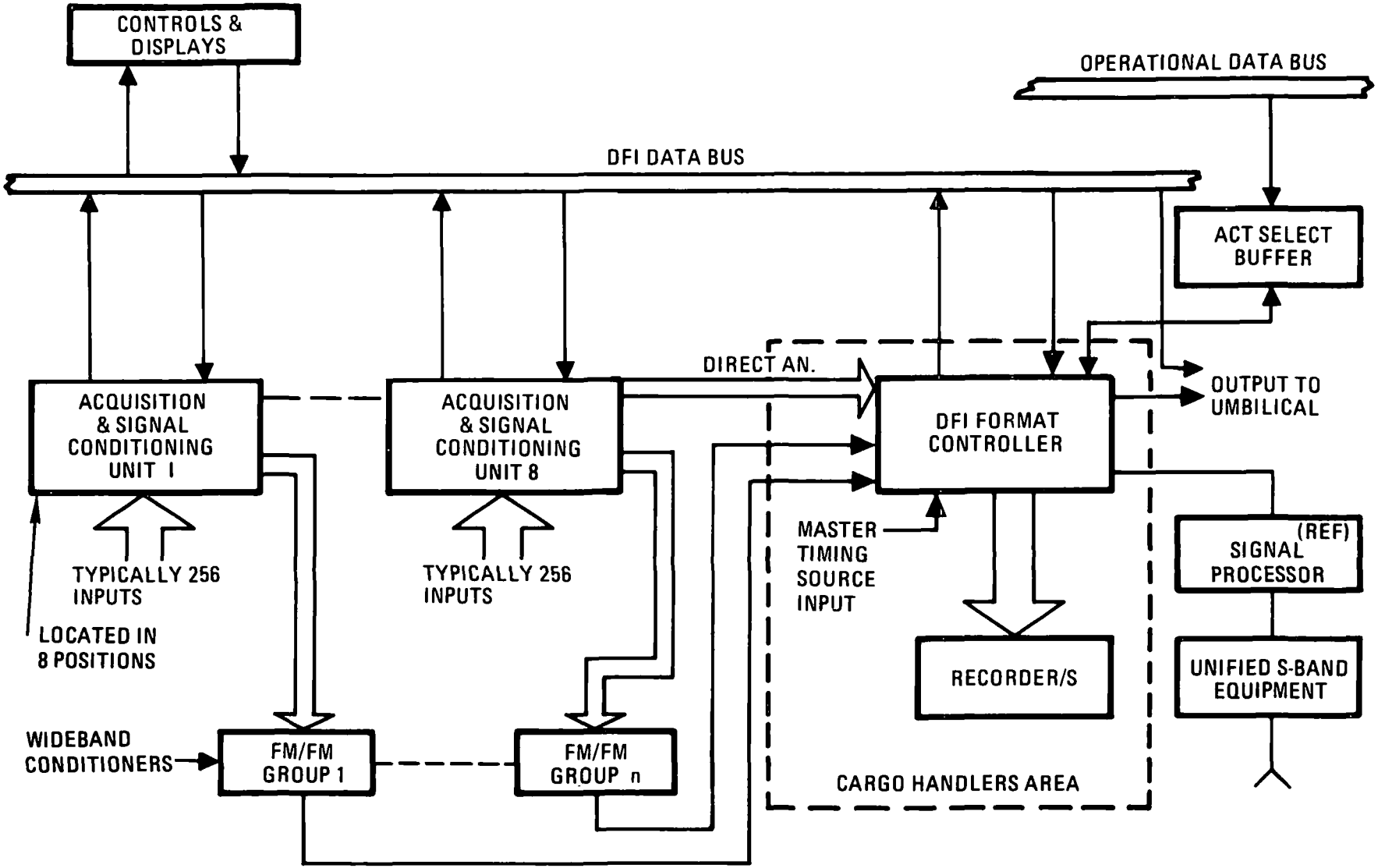


Figure 5-43. Instrumentation Subsystem Schematic

Table 5-32. Instrumentation Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
OPERATIONAL REQUIREMENTS							
1. Ability to remove specified DFI equipment upon completion of flight test program.	P						S
2. Ability of airborne DFI to interface with ground system via umbilical and RF link.					S		P
3. Accessibility of devices requiring periodic calibration.	P						S
4. Ability of all instrumentation elements to operate within performance tolerances under environments specified.			S	S			P
DEVELOPMENT FLIGHT INSTRUMENTATION (DFI)							
1. Compatibility of transducers and conditioners with their functional applications.						S	P
2. Compatibility of transducers and conditioners with the data acquisition multiplexers.						S	P
3. Ability of each black box element of the DFI to condition, multiplex, modulate or record data properly.			S	P			
4. Ability of each element of the DFI to perform in its expected environment.			S	S			P
5. Integrate the black box elements of the DFI into a functional subsystem.					P		
6. Ability to integrate the DFI subsystem with its COMM, DCM, and EPD&C interfaces.						P	
OPERATIONAL INSTRUMENTATION							
1. Compatibility of transducers and conditioners with their applications.						S	P

Table 5-32. Instrumentation Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
2. Compatibility of transducers and conditioners with their ACT interfaces.						S	P
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Electrical circuit continuity and insulation resistance.				P			P
2. All components and assemblies are free of defects and conform to the design requirements.			P	P			
3. Proper transducer installations.				P			P
4. Demonstrate static (and dynamic, when feasible) end-to-end performance of each measurement.						S	P

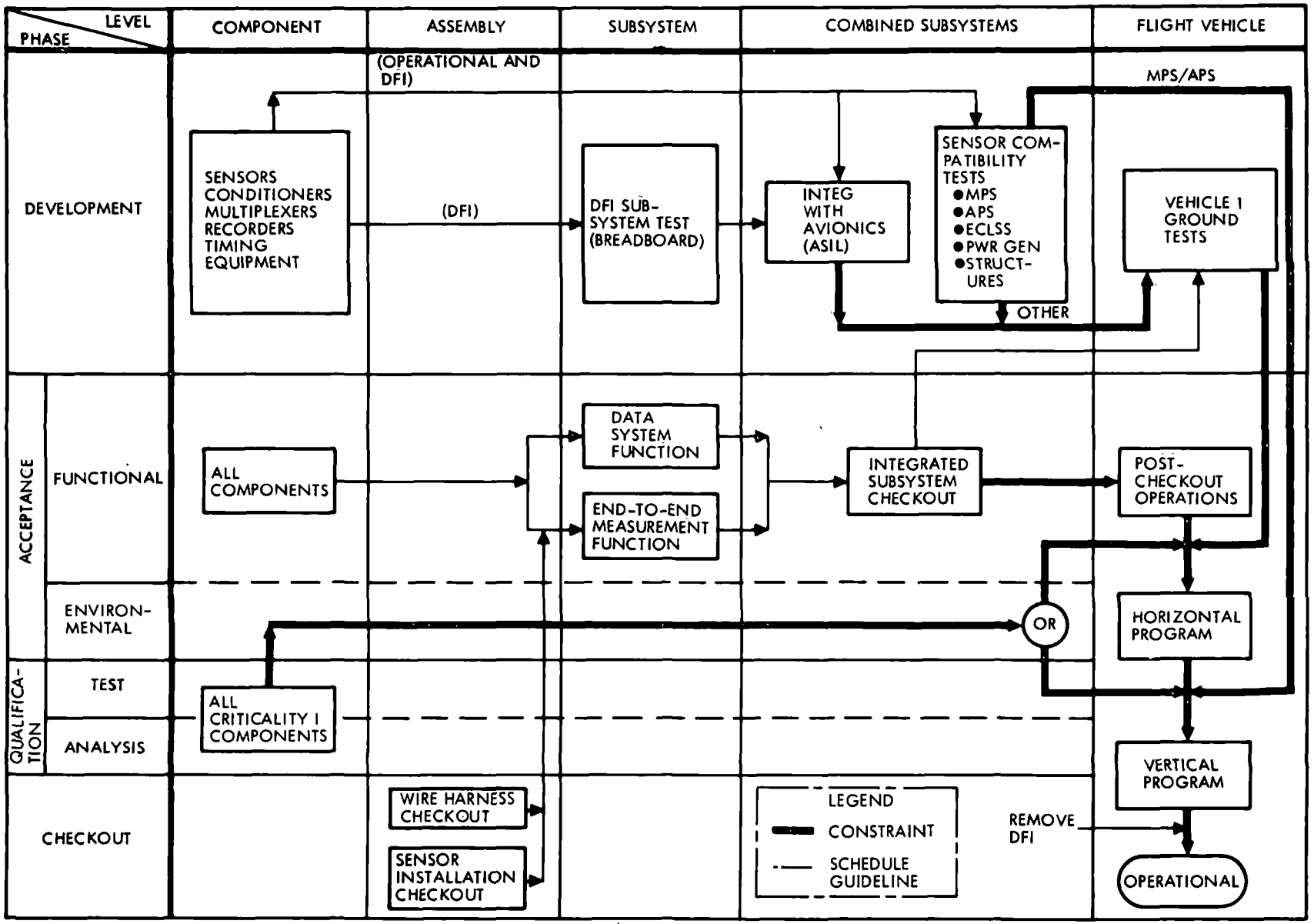


Figure 5-44. Instrumentation Subsystem Test Logic and Constraint Network

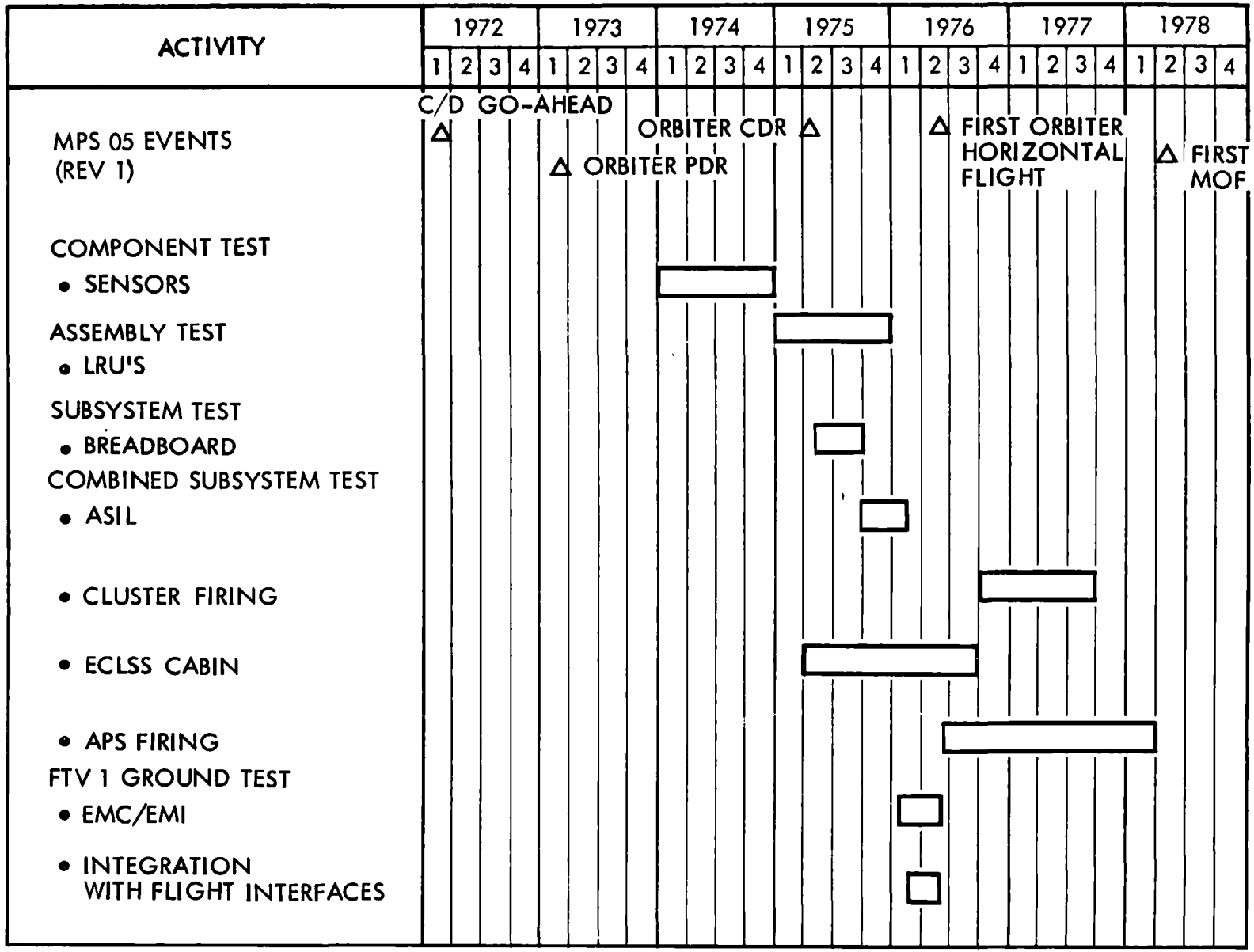


Figure 5-45. Instrumentation Subsystem Test Schedule

Table 5-33. Instrumentation Test Hardware Requirements

Assembly	Subsystem Testing (quantity)	Instrument/Subsystem Compatibility Tests
DFI		
Acquisition and signal conditioner unit	2	
DFI format controller	1	
DFI recorder	1	
Wideband conditioner	1	
ACT select buffer	1	
DFI displays and controls	1	
DFI data bus	20 percent	
Selected transducers and conditioners		As required to support tests of each subsystem
OPERATIONAL		
Selected transducers and conditioners		As required to support tests of each subsystem

Note: The hardware quantities identified are for subsystem level testing, and do not include requirements for development/qualification of individual components and subassemblies. Contractor-utilized test hardware will be reused as required for ASIL combined subsystems testing.

Table 5-34. Instrumentation Test Support Requirements

Area	Requirement
Facility	Electrical power Stimuli for transducer testing (cryogenic, thermal, vacuum, etc.) Air conditioning/heating/ventilation Environmental test capability
Support equipment	Stimuli equipment for transducers Transducer monitor equipment Simulated data sources Data demodulation and analysis equipment Miscellaneous environmental test equipment (Including EMI) Standard laboratory test equipment Test control panel/console
Software	Programs to implement the following: Acquisition and reduction of simulated DFI data Test reporting

5.12 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM (ECLSS)

5.12.1 Description

The ECLSS provides the following: a shirt-sleeve environment, life support resources, and waste management for four persons; thermal control for electronic equipment; heating of hydraulic fluid while in orbit; and heat removal from the fuel cells. Overall arrangement of ECLSS assemblies as shown on Figure 5-46. Subsystem schematics are shown on Figures 5-47 and 5-48.

The heat transport assemblies consist of a water loop in the cabin and a liquid Freon loop outside the cabin. Heat is transferred from the water to the Freon loop via an intercooler. Generally, heat is accepted by the cabin water loop, transferred to the Freon loop at the interchanger, and then rejected from the vehicle via heat sinks in the Freon loop. Heat transfer between the ECLSS, hydraulic power, and power generation subsystems takes place in the Freon loop.

Heat is rejected from the Freon loop using one or more of the following heat sink assemblies: the intercooler is connected to support equipment for cooling while on the ground; sublimators are used during boost and reentry at altitudes over 100,000 feet; the space radiators are used on orbit; the hydrogen evaporator is used during boost and reentry while under 100,000 feet; and a vapor cycle "kit" is used during ferry flight.

The atmospheric and pressure control assemblies maintain total pressure as well as partial pressures of oxygen and nitrogen within the cabin. If cabin pressure drops below a specified value, the emergency oxygen system becomes active and repressurizes the cabin. Oxygen also is supplied to cyclic accumulators used to remove condensate from the humidity control heat exchanger. Nitrogen is supplied to the water system for pressurizing tank bladders.

The humidity and CO_2 control assembly consists of fans, filters, and ducting, for movement of cabin air through a condensing heat exchanger for humidity control, and through a lithium hydroxide charcoal bed for CO_2 and odor removal. Coolant from the heat transport water loop is used in the heat exchanger.

Cabin temperature is controlled by flowing cabin air through a heat exchanger supplied with warm and/or cold coolant, as required. The assembly is augmented by "cold wall" heat exchangers located in the cabin ceiling and floor.

The waste management assemblies allow for collection, vacuum drying, and storage of feces, storage of trash, and for collection and dumping of urine.

The food management assemblies are used for storage, preparation, and serving of meals and beverages.

The fire detection/fighting assemblies provide for sensing and fighting fires in avionics bays.

5.12.2 Requirements

ECLSS test requirements are listed and categorized as to method of verification, on Table 5-35.

5.12.3 Approach and Rationale

Criteria for development of the ECLSS is shown on Figure 5-49 test logic and constraint network

It is anticipated that ECLSS components and major assemblies will be designed, developed, and in some cases qualified, by a subcontractor. Major assemblies will be developed by the subcontractor and integrated on a "breadboard" level. Later these assemblies will be integrated with the crew cabin and other selected orbiter subsystems at a crew cabin/ECLSS laboratory by the orbiter contractor. The test article and crew cabin/ECLSS laboratory is described in Section 6.3. Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, and/or assembly level. Subsystem and combined subsystem level ground-thermal-vacuum testing is not presently planned. Overall orbiter thermal-control test requirements are summarized in Section 6.6.

Overall ECLSS test rationale can be summarized by following a major assembly through various phases of testing.

The CO_2/humidity control assembly consists of a CO_2 removal section, condensing heat exchanger, ducting, fans, and controls. This assembly will be developed and integrated with other elements of the ECLSS and the vehicle in the following sequence:

Individual components will be adapted or developed by respective subcontractors/suppliers.

The subcontractor will design and fabricate ducting to fit the orbiter contractor's cabin design. The ducting and hardware will be assembled, tested and certified for flight use by the subcontractor.

The orbiter contractor will then install the CO_2/humidity/control subassembly, along with other ECLSS subassemblies, into the crew cabin/ECLSS laboratory for combined subsystem testing. This testing is described in detail in Section 6.3. Issues to be certified during this phase are designated for "combined subsystem" test on Table 5-35.

The ECLSS is integrated with all other orbiter systems during integrated ground testing of flight test Vehicle 1. Since the purpose of these tests is to integrate the ECLSS with other vehicle subsystems, actual testing of the ECLSS will not be as extensive as in the crew cabin/ECLSS laboratory.

The first airborne demonstration of the ECLSS will take place during the horizontal flight test program.

Final demonstration of the ability of the ECLSS to support mission requirements will take place during the orbital flight test program. Issues to be verified by flight test are designated as "flight vehicle" on Table 5-35.

A schedule, showing major ECLSS development milestones, is shown on Figure 5-50.

Acceptance testing will verify that the ECLSS has been assembled correctly and installed properly in the orbiter. The vehicle will be built up in several major modules, each with all wiring, piping, and equipment installed and tested. After these sections are assembled to form the orbiter and final interfaces are tested, a functional test will be run on each ECLSS subsystem. This will be followed by integration testing of the ECLSS with other vehicle subsystems.

To support component development and related subsequent requirements of the ECLSS, material and process testing will be performed to evaluate, characterize, select, and substantiate the selection and processing of materials. Areas to be investigated include:

1. The ability of seals, lubricant, and grease materials to function under mission requirements of temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Performance of thermal control coatings during long earth orbital exposure.

4. Compatibility of materials in contact with each other in environments which may result in degradation of properties.

5. Compatibility, stability, and thermal and physical characteristics of fibrous (bulk) insulation.

6. Effects of structural and fluid system corrosion on useful life of critical materials.

7. Optimization of special welding techniques verified by mechanical and nondestructive tests.

8. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

9. Establishment of methods for detecting damage to the exterior surface of the thermal protection system, for determining the effect of damage on the shuttle mission(s) and for determining repair or replacement criteria.

5.12.4 Test Article Requirements

Two facilities or test articles have been defined for this phase of certification; namely the coolant loop development laboratory and the thermal vacuum test facility. Test article requirements for these programs are summarized on Table 5-36. This testing will satisfy certification issues slated for "assembly" level tests on Table 5-35.

5.12.5 Support Requirements

Support requirements for ECLSS assembly level tests are given on Table 5-37.

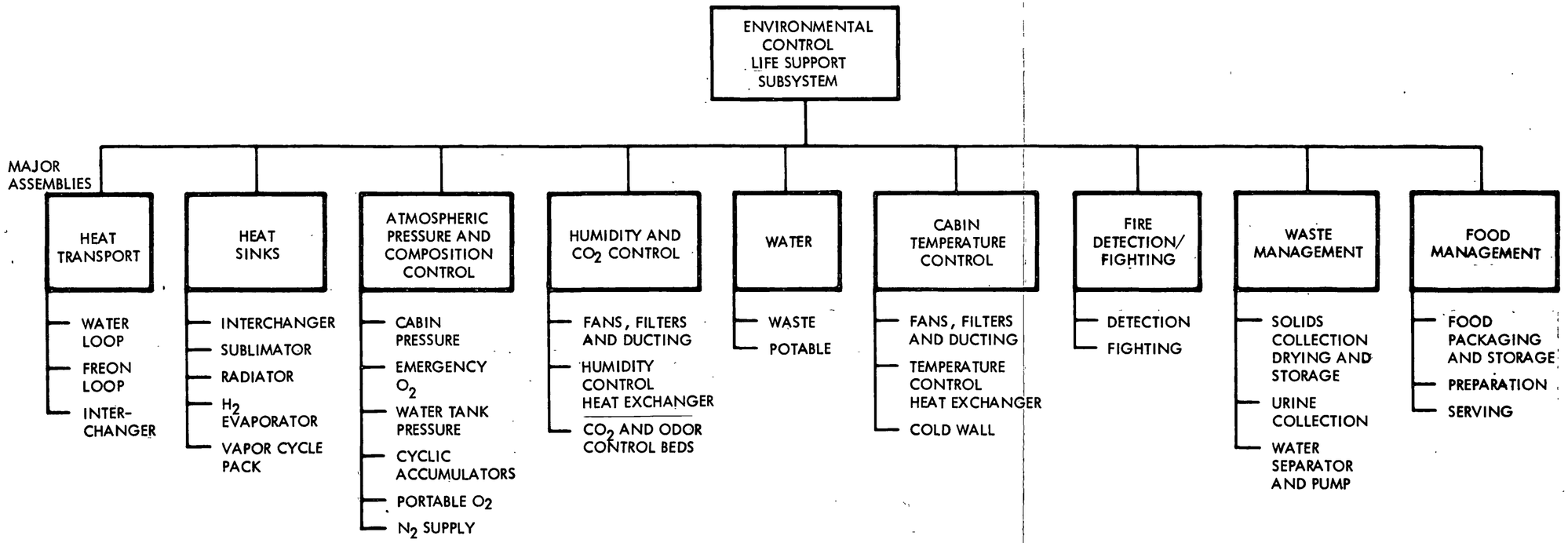


Figure 5-46. Environmental Control and Life Support Subsystem Elements

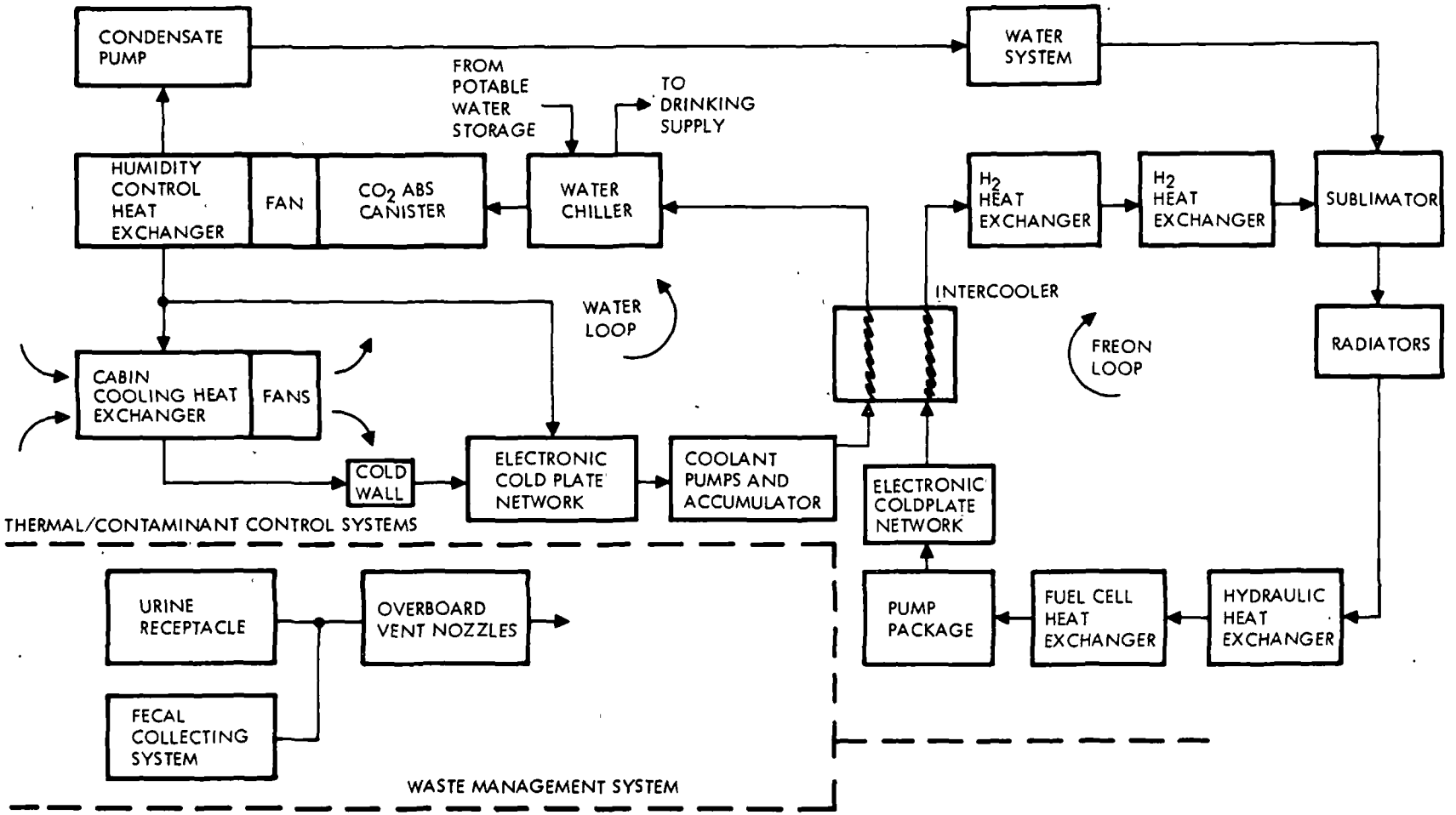


Figure 5-47. ECLSS Subsystem Schematic

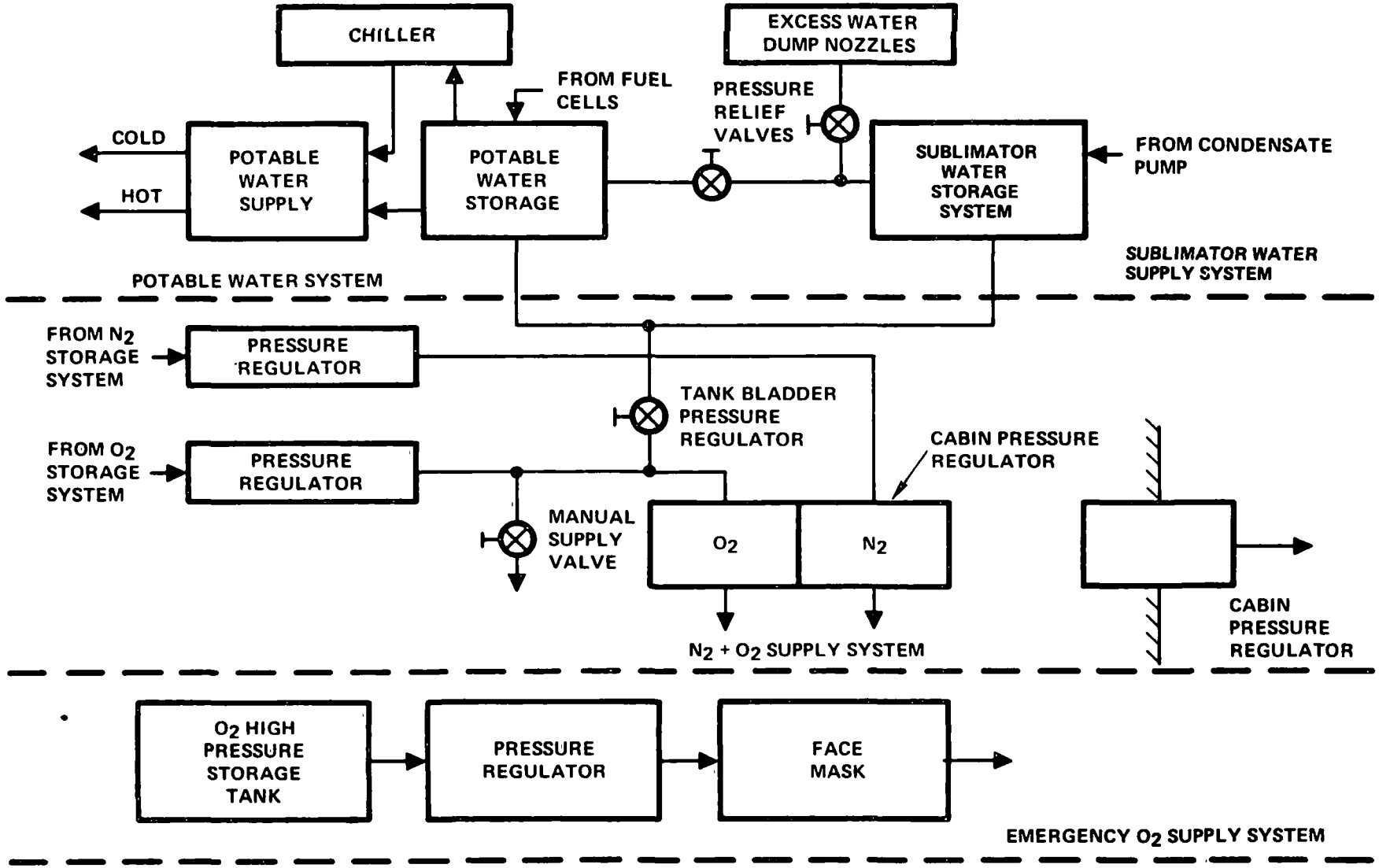


Figure 5-48. ECLSS Water and Pressurization Assemblies

Table 5-35. Environmental Control and Life Support Subsystem Certification Requirements

	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
1.	Conditioned air is distributed without causing discomfort to crew members.						P	
2.	Coldplate network and other heat exchangers are compatible with crew cabin and other ECLSS assemblies.						P P	
3.	Specified heat rejection rates are achieved at coldplates		S		P			
4.	Both automatic and manual controls for the sublimators and the H_2 heat exchangers work within specified limits.						P	
5.	Water assemblies are compatible with crew cabin and other ECLSS assemblies.						P	
6.	Adequate water removal, treatment, and storage from humidity heat exchanger and from fuel cells.						P	
7.	Adequate water is supplied for operation of sublimators and for potable uses.						P	
8.	Water tanks, humidity control heat exchangers, and evaporators can be readily serviced.						P	
9.	CO_2 and humidity control are compatible with other ECLSS assemblies and with the crew cabin.						P	
10.	Automatic and manual controls of the CO_2 and humidity control system achieve design goals.						P	
11.	Air is cooled sufficiently to provide desired humidity levels.		S				P	
12.	Cabin CO_2 level remains within limits						P	
13.	Conditioned air is distributed without discomfort or condensation on any external surface.						P	
14.	Cabin temperature assembly is compatible with other ECLSS assemblies and with the cabin.						P	

Table 5-35. Environmental Control and Life Support Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
15. The cabin temperature assembly can be controlled within limits by either automatic or manual controls.						P	
16. The cabin temperature assembly provides specified amounts of heating and cooling for the cabin air.						P	
17. The pressurization assembly is compatible with cabin and with other ECLSS assemblies.						P	
18. Both normal and emergency cabin pressurization systems keep the pressure within specified limits.						P	
19. The system will accept O_2 from the PRSD and N_2 from the N_2 storage vessel.						P	
20. Sufficient gas is provided for water tank pressurization and cyclic accumulator operation.						P	
21. The N_2 storage vessel can be serviced readily.	S						P
22. The waste management assembly is compatible with crew cabin and other ECLSS assemblies.						P	
23. Ability to dump liquid wastes.							P
24. Solid and liquid waste systems can be used within confines of the crew cabin.						P	
25. The food management assembly is compatible with crew cabin and with other ECLSS assemblies.						P	
26. Provide drinking water and facilities to prepare, serve, and consume meals within confines of crew cabin.						P	
27. Space radiators and associated controls perform within specification.				P			

Table 5-35. Environmental Control and Life Support Subsystem Certification Requirements (Cont)

	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
28.	Sublimators and associated controls perform within specified limits.				P			
29.	All heat sinks in the Freon loops are compatible.				P			
30.	All ECLSS assemblies within the crew cabin are compatible.						P	
31.	The ECLSS responds to management direction of the data control and management subsystem.						P	
32.	Functional performance of redundant subassemblies is within specified limits.						P	
33.	Interface between ECLSS and crew cabin and other orbiter subsystems is within all tolerance limits.							
34.	ECLSS functional performance with other subsystems is within specified limits.							
35.	N_2 vessel, sublimators, water systems, and humidity control heat exchangers are readily serviced.	S					P	
36.	ECLSS must support ground and horizontal flight requirements.							P
37.	ECLSS must support orbital missions.							P
38.	Noise level in cabin from ECLSS operation is within allowable limits.						P	
39.	Automatic and manual controls of the hydraulic and fuel cell heat exchangers are within specified tolerances.						P	
40.	Automatic and manual controls of the three-fluid intercooler are within specified limits.						P	
41.	Heat exchange rates between the water and Freon loops, via the intercooler, are within specified limits.						P	

Table 5-35. Environmental Control and Life Support Subsystem Certification Requirements (Cont)

	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
42.	Fire assemblies are capable of detecting and "fighting" fires in environmentally controlled avionics bays.				P			
43.	ECLSS cooling is provided on the ground by circulation of ground coolant through the intercooler.						P	
44.	The cold wall heat exchangers are compatible with the cabin and with other ECLSS assemblies.						P	
45.	The cold wall heat exchangers and associated controls, in the cabin perform within specified limits.		S				P	
46.	Cold wall floor heat exchangers keep floor temperatures within acceptable levels.							P
47.	The hydraulic subsystem heat exchanger functions within specified limits.						P	
48.	The fuel cell heat exchangers are within specified tolerances.				P			
49.	The strap-on Freon pack acts as heat sink during ferry missions.				P			
50.	Specified ECLSS components and assemblies can withstand mission and ground environments of temperature, pressure, vibration, shock, radiation and weightlessness.	S		P	S			
51.	Crew able to monitor/control ECLSS adequately using displays/controls in the cabin.						P	
52.	Water and Freon pump assemblies meet specified limits while under load in crew cabin.						P	
53.	All redundant components and assemblies meet specified operating requirements.						P	
54.	Cabin pressure fluctuations resulting from normal operation of ECLSS assemblies do not cause crew discomfort.						P	

Table 5-35. Environmental Control and Life Support Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
55. Waste management assemblies control odors within the cabin.						P	
56. Solid waste management assembly is capable of supporting specified functions.				P			
57. Liquid waste management assembly is capable of supporting specified functions.				P			
IN-PROCESS CHECKOUT REQUIREMENTS							
1. The vehicle electrical signal returns single point ground is maintained after harness and distribution box installation.							P
2. No excessive leakage current exists through the harness insulation.							P
3. After installation, harness insulation meets specified limits							P
4. Subsystems are electromagnetically compatible.							P
5. Internal cleanliness of tube system is maintained in accordance with specification.							P
6. Tube systems structural strength is within specified limits							P
7. External leakage through mechanical, brazed, or welded tube joints does not exceed specifications.							P

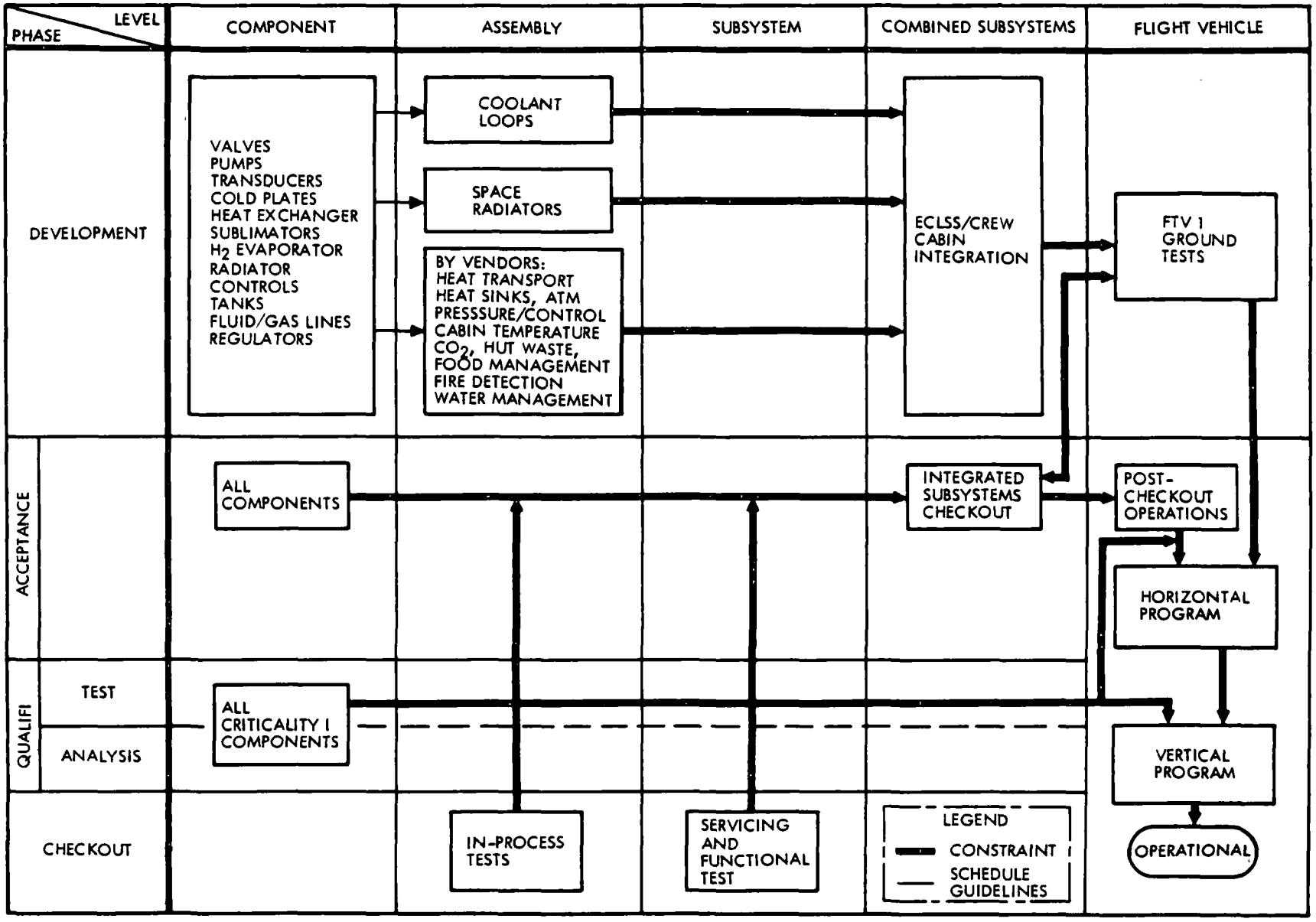


Figure 5-49. ECLSS Test Logic and Constraint Network

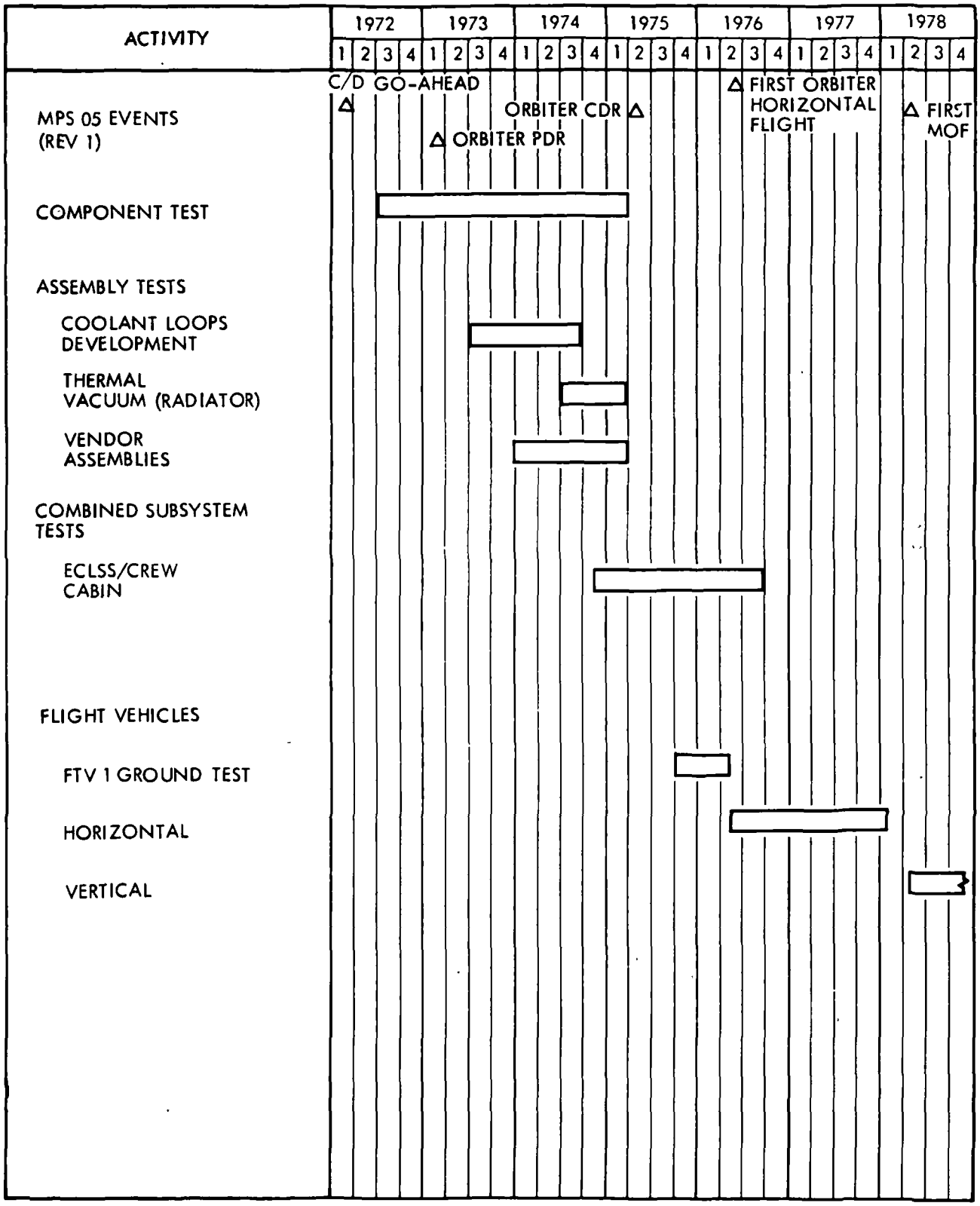


Figure 5-50. ECLSS Test Schedule

Table 5-36. ECLSS Test Laboratory Hardware Requirements (Coolant Loop Development Laboratory and Thermal-Vacuum Radiator Tests)

Assembly	Quantity (percent)
Heat transport	50
Heat sinks (Space radiators included)	50

Note: The quantities listed are for selected assemblies, and do not reflect requirements for all assemblies or for subassemblies or components.

Table 5-37. ECLSS Test Support Requirements

Item	Requirement
THERMAL-VACUUM TEST	
Facility	H_2 storage and transfer Electric power - 60 Hz 3-phase - 120v, 440v; 400 Hz 3-phase - 120v; 28 vdc Water - demineralized, potable Air conditioning GN_2 storage/transfer He storage/transfer Freon storage/transfer Thermo vacuum facility, sized to accept radiator and sublimator; (vacuum level, heating and cooling capacity equivalent to MSC thermo-vacuum test facility)
Support equipment	Ground cooling unit Vacuum pump (for coolant loop servicing) Freon loop servicing unit Test gas regulation/distribution unit Leak detector Test control console
Software	Test control/sequencing Test data processing
Note: The requirements identified are for testing of selected assemblies, and do not include requirements for development or qualification of all assemblies of components.	

Table 5-37. ECLSS Test Support Requirements (Cont)

Item	Requirement
COOLANT LOOP DEVELOPMENT LABORATORY	
Facility	H_2 storage and transfer Electric power - 60 Hz 3-phase - 120v; 400 Hz 3-phase - 120v; 28 vdc Water - demineralized, potable Air conditioning Freon storage/transfer GN_2 storage/transfer H_e storage/transfer Freon disposal
Support equipment	Fixtures to mount coolant loop breadboards Ground cooling unit Coolant pumps (Freon, water) Data system Freon servicing unit Water servicing unit Test gas regulation/distribution Leak detector Liquid mass flow measurement capacity Thermal loads for coldplates
Software	Test control/sequencing Test data processing

5.13 FLIGHT PERSONNEL PROVISIONS, HUMAN FACTORS ENGINEERING, AND CREW ESCAPE SYSTEM

5.13.1 Flight Personnel Subsystem

Description

The flight personnel subsystem consists of both CFE and GFE crew equipment items required by flight personnel for ingress/egress during flight and for survival after an emergency landing. The flight personnel subsystem is schematically illustrated in Figure 5-51. The CFE crew equipment items include both furnishings and equipment whose requirements are similar to corresponding requirements for either current operational multi-engine military or commercial aircraft or the Apollo spacecraft.

Furnishing items consist of flight crew seats, cargo specialist seats, and sleep restraints. The flight crew seats are intended to provide proper body positioning for the flight crewmen so that control of the vehicle can be maintained throughout the mission profile. These seats and the cargo specialist seats, in conjunction with their restraint devices, are intended to provide comfortable support and proper body positioning during vertical launch and horizontal flight conditions, weightless orbital flight, and reentry flight. The sleep restraints are intended to provide both restraint and flight personnel comfort during orbital flight conditions.

Contractor-supplied equipment items consist of emergency ground-descent devices, crew mobility and restraint devices, and stowage containers. The emergency ground-descent device, provided for use as a backup in the event that normal egress routes are blocked or to afford a more rapid egress method in the event of impending danger to on-board personnel, is intended primarily for use in a vehicle-horizontal attitude. Various mobility and restraint devices, provided for personnel ingress/egress on the ground and to ensure the safety, efficiency, and comfort of flight personnel throughout a mission, consist of such items as ladders, handholds, lap belts, shoulder harnesses, and other crew assist devices. Stowage containers consist of both fixed and modularized types. The fixed stowage containers are part of the flight personnel compartment structure, while the modularized containers are part of the flight personnel subsystem.

Requirements

The test requirements for CFE crew equipment items listed in Figure 5-51 have been derived from analyses of design and performance criteria, and from mission-oriented requirements. Satisfactory compliance with these requirements will, in general, demonstrate the feasibility of design concepts,

and the capability of each item of CFE crew equipment to perform its intended function. The flight personnel subsystem test requirements are delineated in Table 5-38 and have been categorized by method of verification.

Approach and Rationale

Crew Equipment Development Requirements. It is anticipated that the majority of crew equipment items that comprise the flight personnel subsystem will be provided by NASA and will be designated as GFE crew equipment. These will consist of items such as personal apparel, personal hygiene aids, and miscellaneous personal effects for flight personnel as well as general crew equipment/supplies, mission-operational aids/equipment, and emergency/safety equipment. As such, no development, qualification/certification, or acceptance tests are customarily performed by the contractor since such equipment will already have been qualified by NASA. However, GFE crew equipment interface requirements with orbiter subsystems and flight personnel must be established and verification test programs must be conducted to assure satisfactory integration of this equipment with the vehicle.

Each item of CFE crew equipment to be provided in the orbiter is either an existing item qualified for aircraft installation or an upgraded version of standard state-of-the-art aircraft or spacecraft hardware that is already qualified. Most testing, therefore, will support the advancement and refinement of these existing concepts and integration of these designs with other orbiter subsystems.

Test Logic. The CFE crew equipment test logic is presented in Figure 5-52. Subsequent to completion of development, qualification/certification, and acceptance testing, it is expected that, prior to vehicle integration testing, each item of CFE crew equipment will be cycled through installation checkout in a high-fidelity mockup. Requirements for integrated systems testing will be satisfied during ground test of the first flight vehicle with exception of the flight crew and cargo specialist seats since these will be installed only in operational vehicles. Final verification of the capability of each item of CFE crew equipment to support mission requirements will occur during the horizontal and orbital flight test programs. Exceptions are the operational vehicles' flight crew and cargo specialist seats and the actual operational usage of the ejection seats required for the flight test vehicles. This latter capability will already have been verified through the sled test program required for crew escape system qualification and customer acceptance.

Crew Equipment Installation Checkout. Installation checkout of the CFE crew equipment items will be performed in a high-fidelity mockup prior to initial orbiter installation for vehicle integration testing. For the purpose

of this initial fit-and-function checkout, this mockup will have high fidelity in at least the discrete areas with which the crew equipment interfaces. With respect to crew seating provisions, initial use of this installation checkout mockup will be for the ejection seats. Since the end-item usage for these ejection seats is the flight test vehicle, this mockup will subsequently be modified to remove all vehicle-related escape system components and install interface and attachment provisions for the flight crew seats. (Refer to Section 5.13.3 for escape system test requirements.)

Crew Equipment Procurement and Integration. Orbiter crew equipment items will be provided both by the contractor (CFE) and by the customer (GFE). Integration of GFE crew equipment with orbiter subsystems will be performed after equipment definition, vehicle interfaces, and verification test requirements have been established.

Crew Equipment Test Philosophy. Development, qualification/certification, and acceptance tests are expected to be minimal for the sleep restraints, personnel mobility and restraint devices, and stowage containers since these items are essentially upgraded Apollo-type hardware. Subsequent to initial checkout in the high-fidelity mockup, the functional operability of these items will be verified during ground testing in the first orbiter vehicle.

The emergency ground descent device is also expected to require only minimal qualification/certification and acceptance testing since an acceptable device, qualified and installed for operational use on both military and commercial transport category aircraft, is readily available.

The flight crew and cargo specialist seats, although requiring possibly unique features of adjustment capability or articulation, are within the present technology. They are expected to possess many similarities to either standard military or commercial aircraft crew seating provisions or to the Apollo couch in articulation requirements. The development, qualification/certification, and acceptance test program required for these items is not considered to be extensive. Installation checkout in the high-fidelity mockup will be performed as discussed above.

Components and subassemblies of all these CFE crew equipment items will require standard, routine development, qualification/certification, and acceptance testing to man-rate them for use in the orbiter and to qualify them for compliance with mission requirements.

Test Schedule. The flight personnel subsystem test schedule is shown in Figure 5-53.

Test Article Requirements

Hardware requirements are listed in Table 5-39.

Support Requirements

Support requirements are summarized in Table 5-40.

Support Equipment. Equipment necessary to support the CFE crew equipment test program will include but not be limited to the following:

1. High-fidelity mockup of flight personnel compartment (for installation checkout of CFE crew equipment items)

2. Structural test fixtures (for conducting structural tests on CFE crew equipment items)

3. Test articles (includes sufficient number of CFE crew equipment items)

Facilities. Facility requirements necessary to support the CFE crew equipment test program will include the following:

1. Structural test laboratory (includes load application devices such as hydraulic rams, data measurement and recording equipment, test areas, shop support function, test article handling equipment)

2. Environmental test laboratory (includes appropriate equipment and provisions for conducting routine environmental testing)

Software. Software requirements necessary to support the CFE crew equipment test program are related to the crew escape system, and are discussed in Section 5. 13. 3.

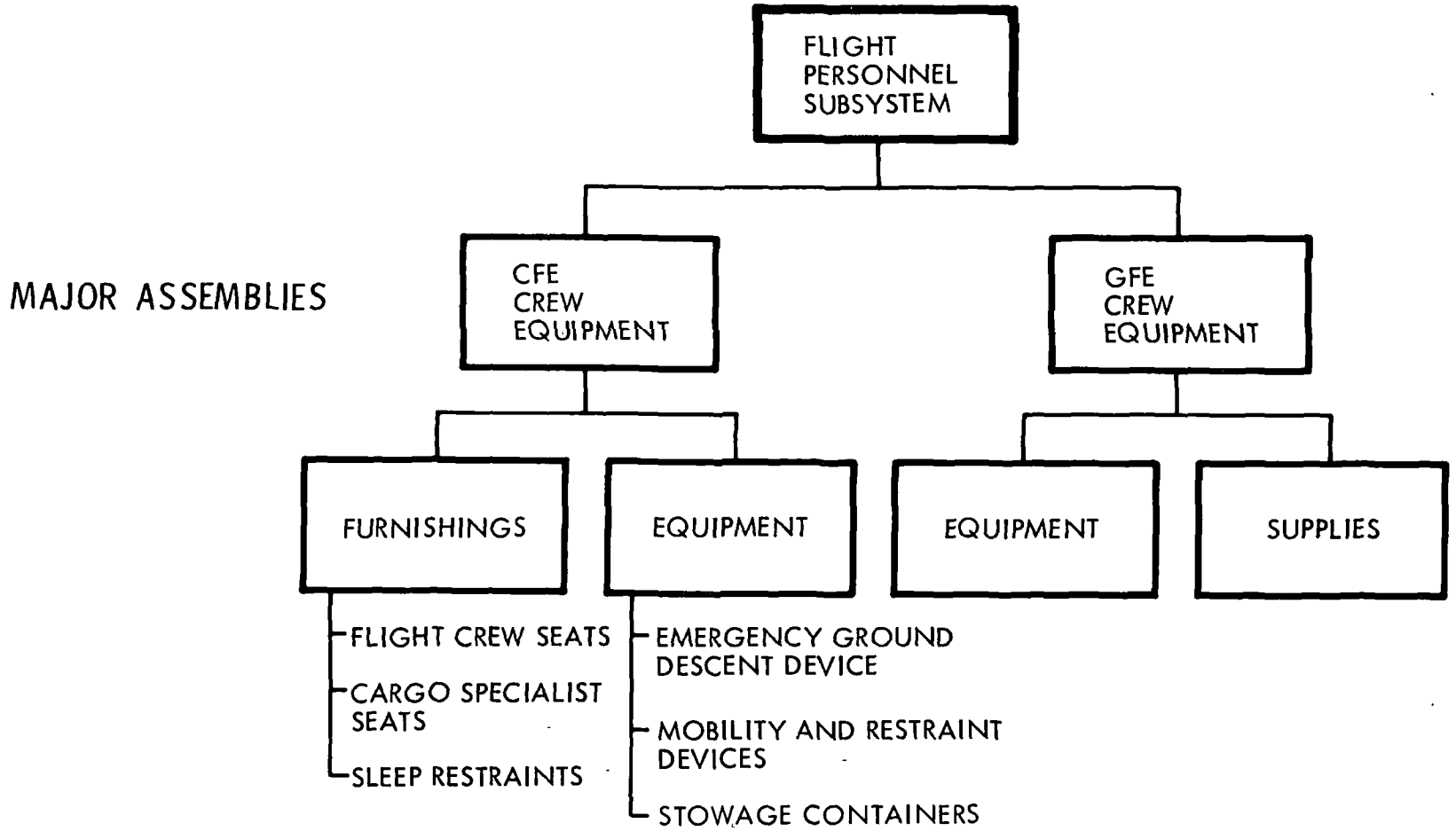


Figure 5-51. Flight Personnel Subsystem Elements

Table 5-38. Flight Personnel Subsystem Certification Requirements

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout*	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
FLIGHT CREW SEATS									
1. Structural integrity of seats under specified flight and contingency (i.e., crash) load conditions	S		S	P					
2. Structural integrity of seat-to-structure attachment fittings under specified flight and contingency (i.e., crash) load conditions	S		P	S					
3. Structural integrity of seats under all anticipated personnel ingress/egress, operational usage, handling, and seat installation/removal load conditions	S		S	P		S	S	S	S
4. Capability of seats to withstand mission and other specified environments (i.e., vibration, temperature extremes, humidity, flammability of non-metallic materials, etc.)	S		S	P				S	S
5. Functional operability of seats in compliance with specification requirements (i.e., seat positioning throughout adjustment range, flight personnel comfort, adequacy of seat and restraint devices to provide safe and acceptable launch, in-flight and reentry support)			S	S		S	P	S	S
**6. Suitability of flight personnel ingress/egress, adequacy of external/internal visibility, and controls/displays accessibility and operability for the design percentile range of flight crew personnel	S					S	P	S	S

*High-fidelity mockup
**Combined subsystem test
Note Flight crew seat certification requirements for Categories 7, 8, and 9 will be met on an operational vehicle, since the flight test vehicles are equipped with ejection seats.

Table 5-38. Flight Personnel Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout*	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
CARGO SPECIALIST SEATS									
1. Structural integrity of seats under specified flight and contingency (i. e., crash) load conditions	S		S	P					
2. Structural integrity of seat-to-structure attachment fittings under specified flight and contingency (i. e., crash) load conditions	S		P	S					
3. Structural integrity of seats under all anticipated personnel ingress/egress, operational usage, handling, and seat installation/removal load conditions	S		S	P		S	S	S	S
4. Capability of seats to withstand mission and other specified environments (i. e., vibration, temperature extremes, humidity, flammability of nonmetallic materials, etc.)	S		S	P				S	S
5. Functional operability of seats in compliance with specification requirements (i. e., seat component articulation and seat positioning throughout adjustment range, flight personnel comfort, adequacy of seat and restraint devices to provide safe and acceptable launch, in-flight and reentry support)			S	S		S	P	S	S
**6. Suitability of flight personnel ingress/egress for the design percentile range of flight personnel	S					S	P	S	S

*High-fidelity mockup
**Combined subsystem test
Note Cargo specialist seat certification requirements for Categories 7, 8, and 9 will be met on an operational vehicle, since the flight test vehicles are equipped with ejection seats

Table 5-38. Flight Personnel Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout *	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
SLEEP RESTRAINTS									
1. Structural integrity of sleep restraints under all anticipated load conditions imposed by operational usage, handling, and personnel ingress/egress	S		P	S		S	S		
2. Structural integrity of sleep restraint attachment fittings, for all anticipated load conditions	S		P	S					
3. Capability of sleep restraints to withstand mission and other specified environments (i. e., temperature extremes, humidity, flammability of materials, etc.)	S		S	P					S
**4. Adequacy of accessibility and retrieval from stowage, ease of installation in the usage location, and ease of removal and restowage	S					S	P		S
5. Functional adequacy as a restraint in weightless orbital flight									P
6. Suitability of personnel ingress/egress and capability to provide for crew comfort in operational usage, in weightless orbital flight									P
EMERGENCY GROUND DESCENT DEVICE									
1. Structural integrity of descent device in compliance with specification requirements				P					
2. Structural integrity of descent device attachment provisions under operational load conditions	S		P	S					

*High-fidelity mockup
**Combined subsystem test

Table 5-38. Flight Personnel Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout*	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
**3. Adequacy of descent device mounting and retention provisions under all anticipated flight load conditions	S		S	P					
4. Capability of descent device to withstand mission and other specified environments (i.e., vibration, temperature extremes, humidity, flammability of materials, etc.)	S		S	P				S	S
5. Functional operability characteristics of descent device in compliance with specification requirements				P					
**6. Adequacy of accessibility and retrieval of descent device for operational usage	S					S	P		
**7. Personnel survival and safety aspects of descent device utilization through timed egress tests, in conjunction with the side emergency egress hatch's functional operability characteristics and egress clearances	S					S	P		
MOBILITY AND RESTRAINT DEVICES									
1. Structural integrity of the mobility and restraint devices under specified ground, flight and contingency (i.e., crash) load conditions	S		P	S			S		
2. Structural integrity of attachment fittings for the mobility and restraint devices	S		P	S			S		
3. Capability of the mobility and restraint devices to withstand mission and other specified environments (i.e., vibration, temperature extremes, humidity, flammability of non-metallic materials, etc.)	S		P	S					S

*High-fidelity mockup
**Combined subsystem test

Table 5-38. Flight Personnel Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
**4. Functional operability of deployable mobility devices in compliance with specification requirements (i.e., ladders, handholds, etc.)			S	S			P	S	S
5. Adequacy of restraint devices (i.e., lap belt, shoulder harness) to safely and efficiently restrain flight personnel under specified flight and contingency (i.e., crash) load conditions	S		S	P			S	S	S
**6. Suitability of the mobility and restraint devices for flight and ground personnel usage during all mission phases (i.e., ground ingress/egress, weightless orbital flight, etc.)	S		S	S		S	P	S	P
STOWAGE CONTAINERS									
1. Structural integrity of the stowage containers under specified flight and contingency (i.e., crash) load conditions	S		P	S					
2. Structural integrity of the stowage containers under all anticipated load conditions imposed by operational usage	S		S	P					
**3. Adequacy and structural integrity of stowage container mounting or retention provisions under all anticipated flight and operational usage load conditions	S		S	P		S	S		
4. Capability of the stowage containers to withstand mission and other specified environments (i.e., vibration, temperature extremes, humidity, flammability of nonmetallic materials, etc.)	S		P	S				S	S
**5. Suitability of stowage container operational usage (i.e., accessibility, ease of equipment retrieval/restowage, dexterity in manipulating latching/securing mechanisms, etc.)	S					S	P	S	S

*High-fidelity mockup
**Combined subsystem test

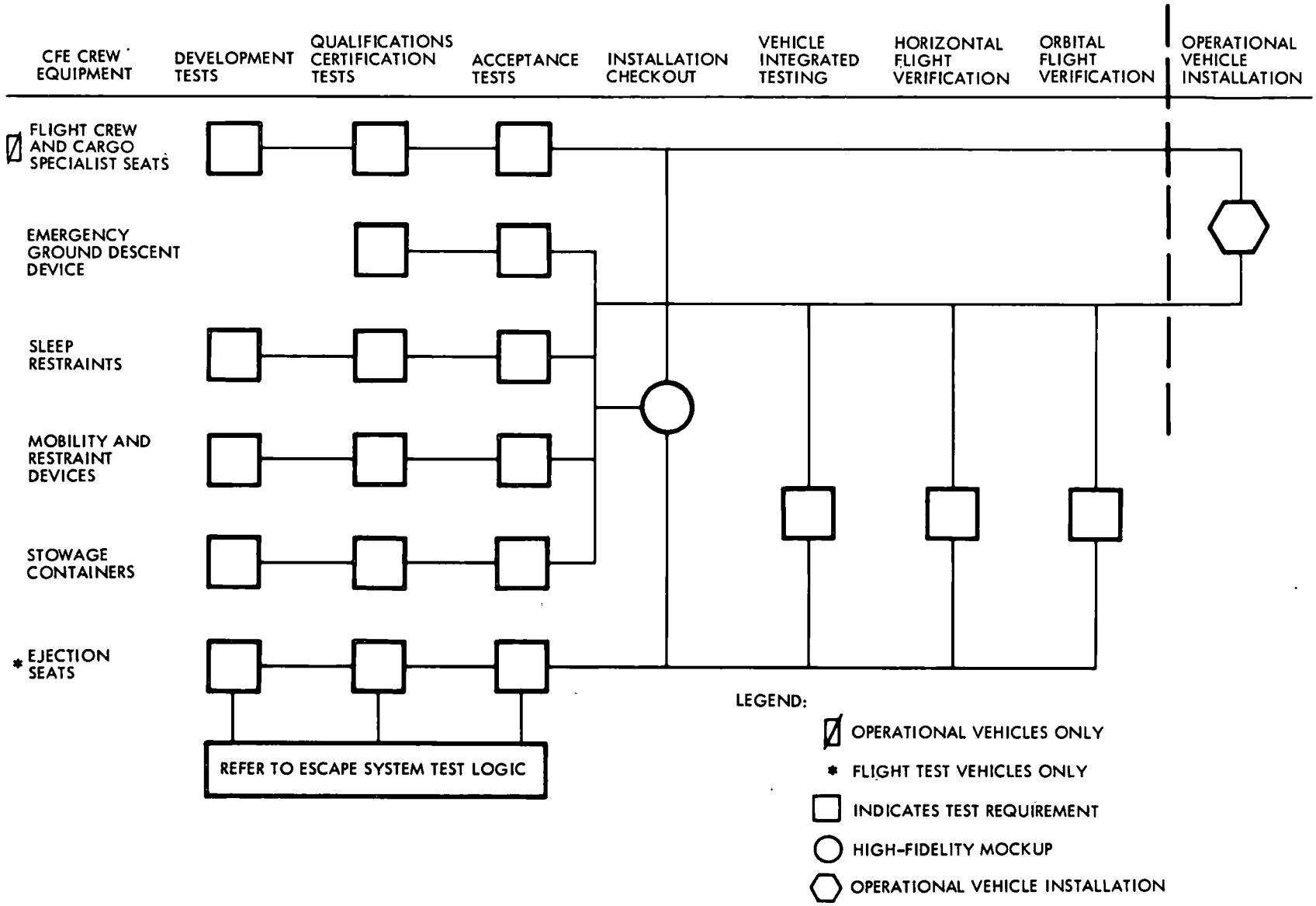


Figure 5-52. Flight Personnel Subsystem Test Logic Network

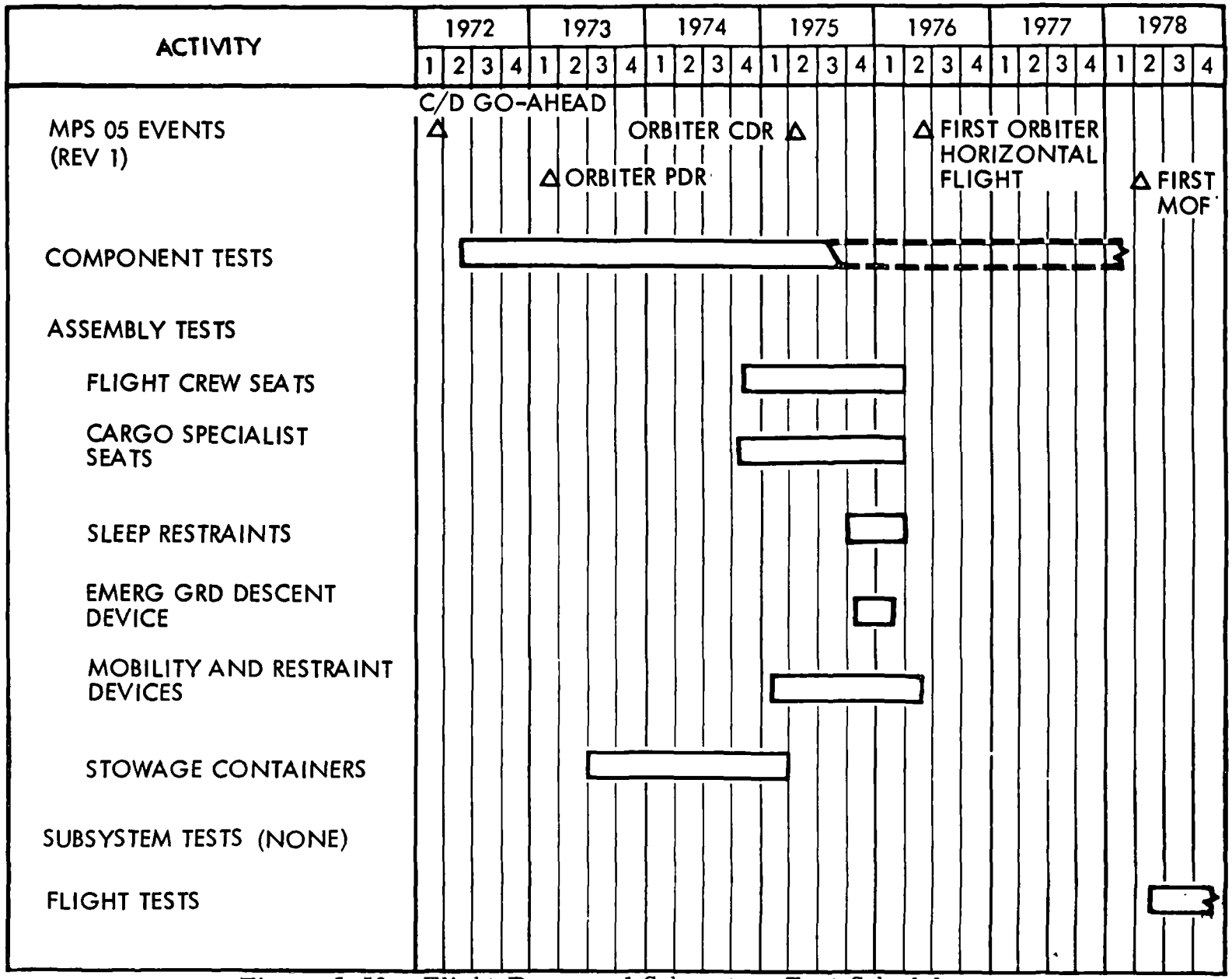


Figure 5-53. Flight Personnel Subsystem Test Schedule

Table 5-39. Test Article Requirements - Flight Personnel Provisions

Assembly	Quantity		
	Structural Tests	Environmental Tests	Other Tests (Type Specified)
Flight crew seat	2	2	2 (functional - retain as spares)
Cargo specialist seat	2	2	2 (functional - retain as spares)
Sleep restraint	2	2	1 (functional - retain as spare)
Emergency ground descent device	2	2	1 (functional - install in mockup)
Mobility and restraint devices (each item)	2	2	1 (functional - install in mockup)
Stowage containers (each item)	2	2	1 (functional - install in mockup)

NOTE: The quantities shown do not include requirements for development or qualification of individual components or subassemblies.

Table 5-40. Support Requirements - Flight Personnel Provisions

Item	Requirement
Facility	Structural test laboratory Environmental test laboratory
Support equipment	Mockups of crew and passenger compartments Structural test fixtures
Software	Refer to Section 5. 13. 3

5.13.2 Human Factors Engineering Testing

Description

Human factors engineering testing involves the use of mockups, models, breadboards, and simulators to develop, evaluate and validate selected design concepts and configurations and to assure crew integration and optimization of man-machine interfaces in compliance with human factors engineering criteria/requirements. This is schematically represented in Figure 5-54.

Habitable portions of the orbiter vehicle and other areas accessible to flight and ground personnel will be developed, tested, and operated with man being an integral part of the total system. An iterative effort will be required in the development of final hardware design, to optimize flight personnel interface requirements and flight personnel compartment integration for effective mission operations. Development tests and evaluations, conducted during system design, are intended to bring human factors considerations to bear on system design decisions. Verification tests and evaluations, performed with suitable mockup or prototype hardware, are intended to verify within practical limits that the hardware is compatible with human engineering requirements.

Requirements

The requirements for human factors engineering development/evaluation/verification testing have been derived from analyses of design and performance criteria, requirements and recommendations previously developed, and requirements imposed by mission objectives. Interior arrangements, flight personnel provisions, and crew operational interfaces must be evaluated during systems evolution to assure that the final configuration provides for safe, efficient, and comfortable operation by flight personnel.

Human factors engineering test requirements are grouped and delineated in Table 5-41, and have been categorized by method of development/evaluation/verification. In this context, test category number four, designated "Assembly or Subassembly", is intended to include mockups, models, breadboards, and simulators as applicable to the specific requirement under consideration.

Approach and Rationale

Human Factors Engineering Test Methodology. Mockups will be created and utilized to develop, assess, and validate design features/configurations to verify compliance with human factors engineering criteria and requirements; and to evaluate crew procedures and operational inter-

faces. Fixed-base dynamic simulation programs will be provided to exercise specific orbiter subsystems as they are developed, to evaluate man-machine interfaces, to assess crew operational procedures/techniques, and to demonstrate the capability to fulfill crew operational and mission requirements.

Test Logic. Human factors engineering test logic is depicted in Figure 5-55. From selected human factors and subsystem requirements related to the area of interest, an analysis will first be performed to establish the test category (i.e., development, evaluation, verification), to define test objectives and data to be derived; and to determine test parameters and specific mockup requirements, provisions, and support equipment required for conduct of the test.

A detailed test plan will be prepared; and the test will be conducted employing test subjects, facilities, and support equipment as required. The test results will then be documented and provided to cognizant technical areas with appropriate recommendations for design implementation.

Specific Areas of Interest. In the overall development and verification of interior arrangements, flight personnel provisions, and crew operational interfaces, areas of significant interest that have been identified during the Phase B portion of the program are discussed in the following paragraphs. Mockup requirements and considerations are included for each of these areas. Of particular interest, because of the orbiter's unique dual-operational attitudes (both horizontal and vertical flight modes), will be the development and verification of provisions and procedures required for flight personnel ingress/egress including occupants of a cargo bay personnel module. In addition to normal ingress/egress considerations, safe, rapid emergency egress provisions and procedures as well as rapid ingress capabilities for rescue operations on the pad or at the landing site must be developed, evaluated, and implemented. Although the dual-mode requirements for these particular functions are considered to be unique in an aerospace vehicle, no significant problem areas are presently anticipated.

Flight crew external visibility is also a matter of interest because of potential constraints imposed by vehicle structural requirements, inner-outer moldline relationships, impact of the thermal environment on glass surfaces during boost and reentry, and the interrelationships between windshield angle moldline slope), internal/external illumination, and reflectances. This last factor also influences flight crew internal visibility.

Human factors engineering testing will require provision of a hard mockup of the flight crew station. Development and verification of suitable man-machine interfaces and operational procedures for the payload deployment/retrieval system is also a matter of considerable interest. Evaluation of flight personnel/subsystem interfaces and operational

procedures for payload deployment/retrieval will require provision of a hard mockup of the payload handling station.

The development and validation of an acceptable docking system for the orbiter is an area of particular interest. The use of both mockups and dynamic simulations will be required to develop and verify suitable man-machine interfaces and operational procedures, to validate the operability and efficiency of candidate systems, and to demonstrate overall systems compatibility with performance capabilities and limitations of flight personnel. Evaluation of flight personnel/subsystem interfaces and operational procedures for docking activities will require provision of a hard mockup of the docking station.

Test Schedule. The schedule for human factors engineering development and verification testing is shown in Figure 5-56.

Test Article Requirements

Test article requirements appear in Table 5-42.

Support Requirements

Test hardware equipment to support human factors engineering development, evaluation, and verification testing are summarized on Table 5-43.

Support Equipment. Equipment necessary to support the human factors engineering test program will include but not be limited to the following.

1. Mockup stands, platforms, and personnel access devices
2. Access/viewing platforms for test personnel and observers
3. Test subject apparel and protective devices (i.e., coveralls, "bump" hats, etc.)
4. Test subject safety equipment (i.e., harness, tether, etc., for vertical mode tests)
5. Workspace analyzer equipment (includes miscellaneous assortment of tools)
6. Anthropometric measurement devices and grids
7. Force and torque measurement devices
8. Photographic documentation support

9. Communications equipment (includes console, instrumentation and mockup interface equipment)

10. Pressure garment assembly support equipment (includes PGA test stand, PGA portable ventilation/cooling consoles, three-man pressurization/ventilation control console, bioinstrumentation console for test subject physiological monitoring, certified air supply)

11. Portable air-conditioning units for mockups (interior air ventilation/cooling)

Facilities. Facility requirements necessary to support the human factors engineering test program will include but not be limited to those in the following listing. Items for which specific requirements have not been defined at this time, but which potentially may be required, are indicated by an asterisk(*).

1. Mockup test/display area (includes test area, shop support function, equipment storage facilities, test subject dressing room, rest room with shower facilities, conference room, office area, observation area with stands and platforms, overhead crane for handling mockups, electrical power, air conditioning, plumbing system for certified air supply, mockup interface provisions)

2. Simulation complex (includes control center, digital computer center, analog computer center, test area for mockup/simulator, external visual display equipment such as closed circuit television or projector and screen, grid pattern panels for field of view measurements, communications provisions, simulator operator control provisions, mockup/simulator interface equipment)

3. Dark Room for lighting mockup (includes light barriers/ labyrinth at entryway, special wall treatment for nonreflectance, portable high-intensity spotlights to simulate sun-shafting, control consoles, mockup interface equipment)

4. Human factors laboratory area (includes universal workspace analyzer for rapid and convenient three-dimensional representations)

5. Biomedical laboratory area (includes physiological, exercise and biomedical measurements equipment for test subject conditioning, test data reduction capability, conference room, rest room, office area)

*6. Slow-rotation centrifuge

*7. Six-degree-of-freedom tractionless simulator

8. Neutral buoyancy facility (includes water immersion tank, water heating and filtering system, caisson with viewports for observers and photographic documentation, work stands over tank, laboratory/instrumentation area, office area, equipment storage facilities)

9. Zero-g test aircraft, KC-135 (NASA-furnished)

10. Pressure garment assembly support function (includes test subject dressing room, controlled environment work room and maintenance/repair area, closed classified security area for PGA storage, equipment handling/storage facilities, PGA support equipment)

Software. Software requirements to support dynamic simulator usage in the human factors engineering test program will be as specified in the guidance, navigation and control section, paragraph 5.6. Computer-simulated programs will be required for such mission events as docking and approach/landing.

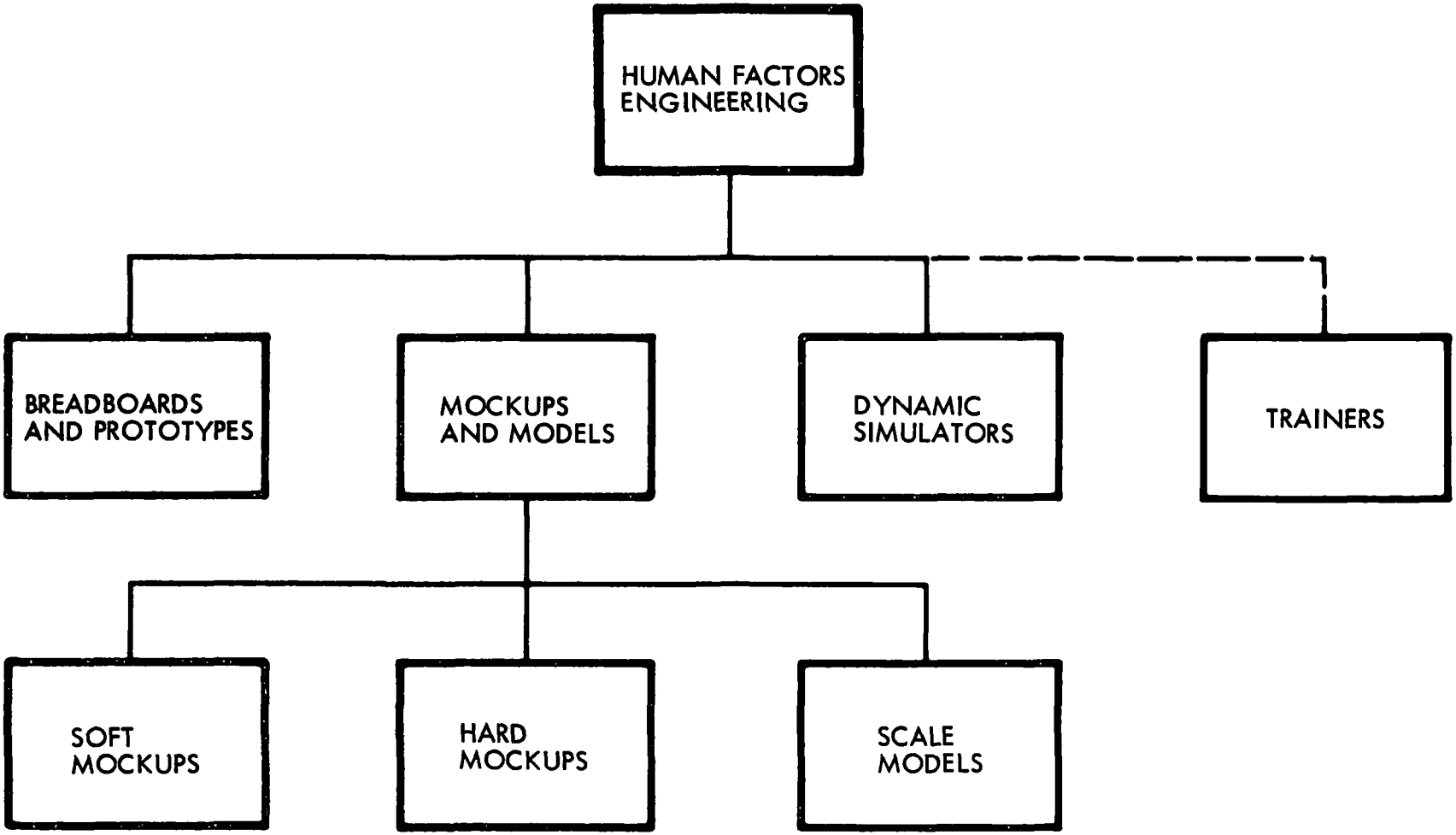


Figure 5-54. Human Factors Engineering Testing Subsystem Elements

Table 5-41. Human Factors Engineering Certification Requirements

Certification Requirement	Certification Category						
	1 Analysis	2 Computer/Model	3 Component	4 Assembly	5 Subsystem	6 Comb. Subsystem	7 Flight Vehicle
1. Flight crew habitability provisions and compatibility with interior arrangements (horizontal and vertical attitudes) for							
a. Mobility	S			P		S	S
b. Accessibility	S			P		S	S
c. Vision	S			P		S	S
d. Reach	S			P		S	S
e. Equipment Operability	S		S	P		S	S
f. Man-Machine Interfaces	S			P		S	S
2. Provisions and procedures supporting the following personnel movements to and from habitable areas of the Orbiter (horizontal and vertical attitudes):							
a. Flight Personnel Routine Ingress/Egress	S			P		S	
b. Flight Personnel Emergency Egress	S			P		S	
c. Rescue Personnel Emergency Ingress/Egress	S			P		S	
3. Adequacy of flight crew external visibility to fulfill crew operational and mission requirements	S			P		S	S
4. Controls/displays arrangements and flight crew station illumination levels for							
a. Vision	S			P		S	S
b. Reach	S			P		S	S
c. Controls Accessibility	S			P		S	S
d. Controls Operability	S		S	P		S	S

Table 5-41. Human Factors Engineering Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
5. Adequacy of flight personnel man-machine interfaces and operational procedures/techniques for the following mission phases:							
a. Launch		P		P			S
b. Ascent		P		P			S
c. Staging		P		P			S
d. Rendezvous/Docking	S	P		P			S
e. Payload Deployment/Retrieval	S		S	P			S
f. Entry/Transition	S	P		P			S
g. Cruise		P		P			S
h. Approach	S	P		P			S
i. Go-Around		P		P			S
j. Landing	S	P		P		S	S
k. Takeoff	S	P		P		S	S

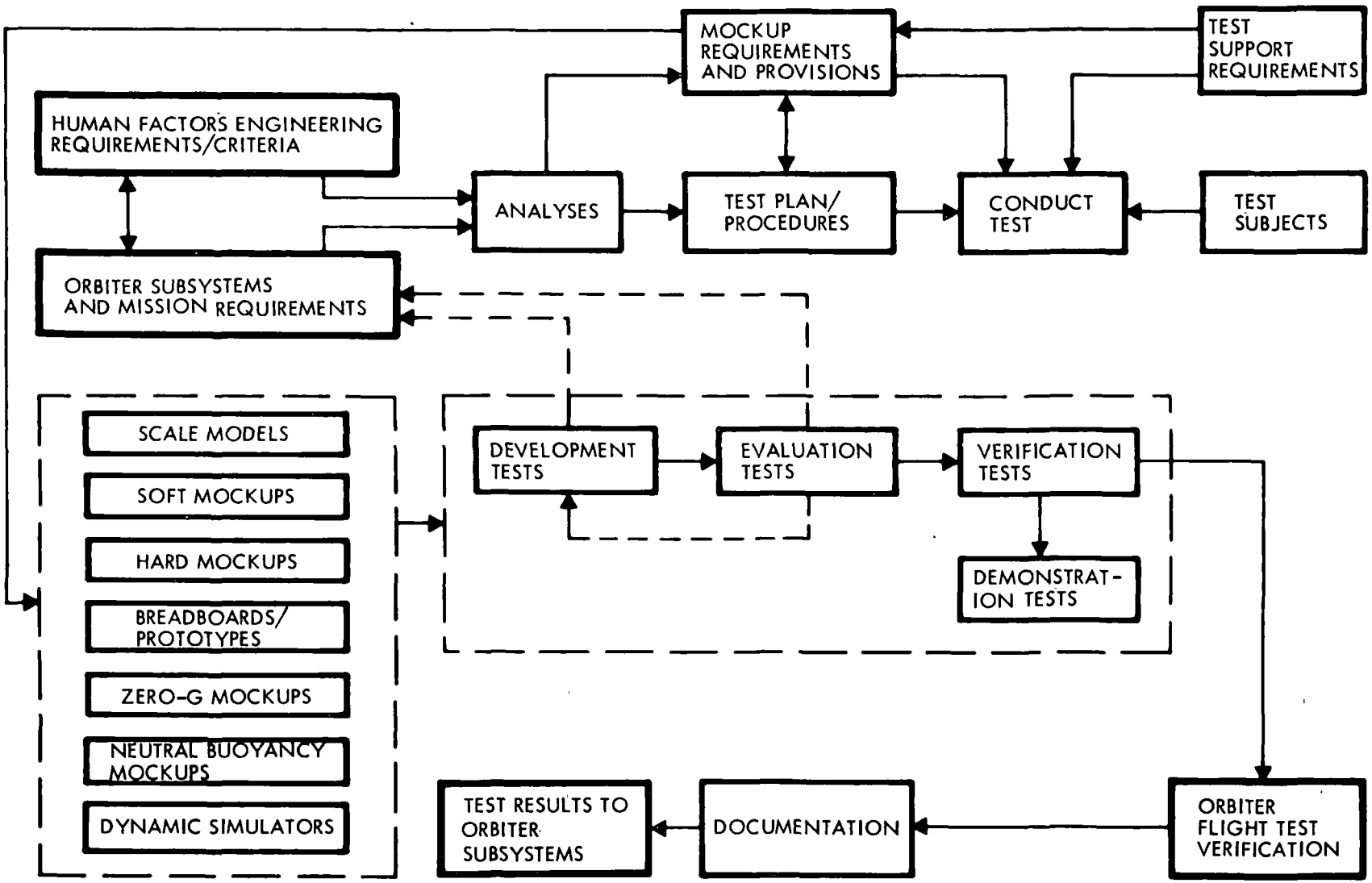


Figure 5-55. Human Factors Engineering Test Logic

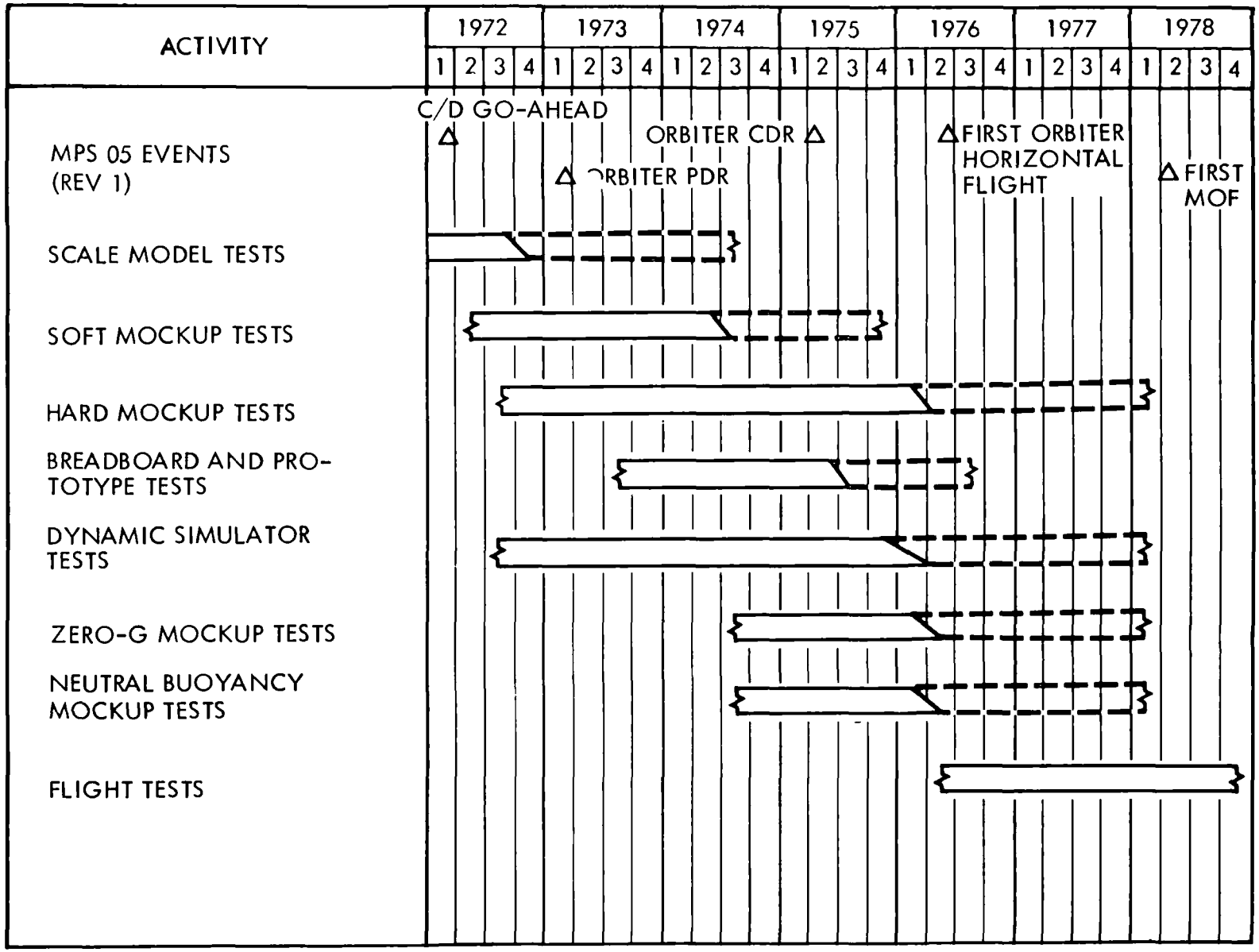


Figure 5-56. Human Factors Engineering Test Schedule

Table 5-42. Test Article Requirements - Human Factors Engineering Testing

Test Article	Quantity
Scale Models	
Flight personnel compartment through cargo bay (1/20 scale)	1
Cargo bay personnel module (1/20 scale)	1
Flight crew station (1/4 scale)	1
Soft mockups (full-scale)	
Flight crew station	1
Food/water management area	1
Waste/hygiene management area	1
Subsystem equipment compartment	1
Tunnel	1
Docking station	1
Payload handling (manipulator) station	1
Hard Mockups (full-scale)	
High-fidelity mockup for crew equipment installation checkout	1
Flight personnel compartment (horizontal and vertical orientations)	2
Flight crew station lighting mockup	1
Airlock	1
Subsystem equipment compartment	1
Tunnel	1
Docking station	1
Payload handling (manipulator) station	1
Partial mockup of cargo bay (forward section)	1
Cargo bay personnel module (horizontal and vertical orientations)	2
Breadboard/prototypes (scaled, full-size or nonscalar)	
Food/water management area	1
Waste/hygiene management area	1

Table 5-42. Test Article Requirements - Human Factors Engineering Testing (Cont)

Test Article	Quantity
Zero-G and Neutral Buoyancy Mockups (full-size or spatial representation)	
Flight personnal compartment	1
Airlock	1
Subsystems equipment compartment	1
Tunnel	1
Partial mockup of cargo bay (forward section)	1
Cargo bay personnel module	1
Dynamic Simulators	
Flight crew station	1
Docking station	1
Payload handling (manipulator) station	1

Table 5-43. Support Requirements - Human Factors Engineering Testing

Item	Requirement
Facilities	Mockup test/display area Simulation complex Darkroom for lighting mockup Human factors laboratory area Biomedical laboratory area Slow rotation centrifuge Six degree of freedom tractionless simulator Neutral buoyancy facility Pressure garment assembly support function Zero-g Test Aircraft (KC-135)
Support equipment	Mockup stands, platforms, personnel access devices Test subject apparel, safety equipment Workspace analyzer equipment Anthropometric measurement devices and grids Force and torque measuring devices Photographic documentation support Communications systems

Table 5-43. Support Requirements - Human Factors Engineering Testing (Cont)

Item	Requirement
Support equipment	Pressure garment assembly support equipment Portable air conditioning for mockups
Software	Miscellaneous programs for operation of simulators, acquisition of data, and analysis of data (refer to Section 5.6 - Guidance, Navigation and Control).

5.13.3 Crew Escape System

Description

Orbiter flight test vehicles will be equipped with ejection seats rather than the flight crew seats to be provided in operational vehicles. In addition to providing the same capability as the flight crew seats with respect to proper body positioning and support throughout the various flight modes, these ejection seats are intended to provide emergency in-flight crew escape capability if abandonment of a flight test vehicle is required. Vehicle-mounted components of the crew escape system include rails for the ejection seats and jettisonable hatches to provide an egress path for the ejection seat and occupant. The crew escape system is schematically illustrated in Figure 5-57.

Requirements

The test requirements for the crew escape system have been derived from analyses of design and performance criteria, from mission-oriented requirements, and from personnel safety requirements dictated by potential hazards inherent in flight testing high-performance airborne vehicles. Satisfactory compliance with these requirements will demonstrate the capability of the crew escape system to perform its intended function. Test requirements are delineated in Table 5-44 and have been categorized by method of verification.

Approach and Rationale

Crew Escape System Development Requirements. The crew escape system (ejection seats and vehicle structural and functional components related to their operation) will provide the capability for safe recovery of the flight crew if emergency in-flight escape from the orbiter is required within the defined escape envelope. Although the ejection seats to be provided for the flight test vehicle crew escape system will be a modified and upgraded version of standard, military aircraft hardware, they will require a sophisticated test program.

Test Logic. The test logic for the emergency in-flight crew escape system is shown in Figure 5-58, and represents an expansion of the development, qualification/certification, and acceptance test requirements. Development and qualification/certification tests will be first conducted on both ejection seat components and subassemblies and on vehicle-mounted or integral components and subassemblies related to the crew escape system. Structural, environmental, and functional (static and dynamic) tests will then be conducted to develop and quality/certify the total escape system in

compliance with specification requirements. Upon completion of this test phase, demonstration/acceptance testing will be performed in the finalization of the sled test program. Test logic subsequent to customer acceptance is as shown in Figure 5-58.

Crew Escape System Test Philosophy. An existing, qualified ejection seat will be selected for the orbiter flight test vehicles which will be capable of safe crew escape within most of the atmospheric flight regime. Emergency crew escape system studies indicate a preference for a high performance open ejection seat which would successfully fulfill projected crew escape contingencies during horizontal and vertical flight modes. Figure 5-59 depicts performance envelope summaries of representative crew escape systems candidates examined during study. The selected escape system for flight test vehicles will be a flight performance envelope capable of 0 to 70, 000-foot altitude and 0 to 2100-FPS velocity with a maximum-2000 PSF q capability. For prelaunch on-the-pad crew escape requirements during the brief interval after tower access arm swing-away and liftoff, a stationary pad ejection could be successfully attained utilizing the zero-zero escape capability inherent in the selected seat

Structural load tests will be performed on the modified ejection seat, as well as on the vehicle-mounted related structure (i.e., seat rails, rocket catapult fulkhead fittings, bulkhead reinforcements), both single and in combination.

Modifications to the pyrotechnic sequencing system of other escape system ordnance devices will require requalification breadboard tests including test firings at ambient, low, and high temperatures.

Various functional static structual tests will be required, some of which are related to operation of ejection seat ordnance devices, to qualify the orbiter's escape system. A series of functional ground tests, both structural and ballistic in nature, will be required to qualify the orbiter's crew escape system. However, the number of tests necessary for qualification is expected to be minimized through selection of an existing ejection seat with modifications incorporated to satisfy specific orbiter application requirements.

Full-scale functional dynamic testing of the integrated crew escape system (i.e., ejection seat, vehicle hatch, pyrotechnic initiation/sequencing system) will be performed via a conventional sled test program. A series of development and qualification tests will be conducted, in which seat ejections will be effected at representative speeds related to the escape system's performance envelope.

Data will be acquired and analyzed on the following parameters in the development and qualification of the Orbiter's crew escape system.

1. Pre-ejection sequences (packaging of seat occupant including powered retraction and torso restraint and deployment/engagement of limb restraint devices to prevent flailing)

2. Structural and functional integrity of seats and hatches (pre- and post-ejection)

3. Postejection trajectories of seats and hatches (including high-speed fin-tip clearance, lateral separation of seat trajectories, probability of seat-occupant collision or entanglement with jettisoned hatches)

4. Aerodynamic characteristics of seat-occupant combination

5. Stability of seat-occupant combination in free flight (seat drogue chute stabilization characteristics, low-speed dynamic stability, high-speed aerodynamic stability)

6. Acceleration/deceleration patterns at the occupant's head, chest, and combined seat-occupant center of gravity (during ejection and postejection, verify within physiological limitations on acceleration/deceleration and rotational rates),

7. Postejection separation of seat and occupant (controlled positive separation, personnel parachute deployment time, probability of seat/parachute entanglement),

8. Low-altitude parachute recovery of occupant (low and high speeds and minimum time from ejection initiation to recovery)

9. Effect of ejection sequence on vehicle (flight crew station noise level and pressure variations subsequent to hatch jettison, vehicle structural integrity subsequent to hatch jettison/seat ejection).

Test Schedule. The crew escape system test schedule is shown in Figure 5-60.

Test Article Requirements

Hardware requirements are listed in Table 5-45.

Support Requirements

Support requirements are summarized in Table 5-46.

Support Equipment. Equipment necessary to support the crew escape system test program will include but not be limited to the following:

1. High-fidelity mockup of flight personnel compartment (for installation checkout of ejection seats, rails, and hatches)

2. Structural test fixtures (for conducting structural tests on crew escape system components and subassemblies)

3. Static firing test stand for static firing ground tests of crew escape system, representative of vehicle horizontal orientation

4. Static firing test tower for static firing ground tests of crew escape system, representative of vehicle vertical orientation

5. Sled test vehicle (simulated orbiter structure representative of the upper fuselage section, which contains the flight crew station and is mounted on a rocket-propelled sled, including on-board instrumentation and remote controlled high-speed motion picture photographic equipment)

6. Anthropormorphic dummies for static firing and sled crew escape system tests (5th and 95th percentile dummies required) including telemetering equipment and instrumentation such as rate gyros, accelerometers, and pressure transducers

7. Motion picture photographic support (both high-speed and standard-speed for static firing and sled crew escape system tests including automatic tracking capability)

8. Personnel parachutes for recovery of dummies used in static firing and sled crew escape system tests

9. Test articles (includes sufficient number of ejection seats and vehicle-mounted escape system related hardware to support the Crew Escape System Test Program).

Facilities. Facility requirements necessary to support the crew escape system test program will include the following:

1. Structural test laboratory including load application devices such as hydraulic rams, data measurement and recording equipment, test areas, shop support function, test article handling equipment

2. Environmental test laboratory including appropriate equipment and provisions for conducting routine environmental testing

3. Static firing test range for static ground tests of crew escape system, subcontractor facility or Government facility such as China Lake, California

4. High-speed track test facility including test track, ordnance support for sled test vehicle, trackside receiving and recording facilities for telemetered test data, trackside high-speed and standard-speed motion picture photographic support, instrumentation and calibration facilities, photographic processing services, data reduction facilities and services, and support personnel services (Government facility such as Holloman AFB, New Mexico, and China Lake, California, or leased facility, Hurricane Supersonic Research Site, Utah).

Software. Software requirements to support the crew escape system test program will be provided by the ejection seat subcontractor. Computer programs will be utilized for processing, correlating, calculating, and presenting test data. These will include such considerations as analyses of dynamic seat-man center-of-gravity/rocket thrust vector relationships, seat system sequencing modes, combined seat-man weight and static center of gravity location for crew percentile range, combined seat-man moment of inertia determinations, and extrapolation of predicted escape system performance at maximum altitude/Mach number and low altitude/high sink-rate modes based on static ground firings and sled test data.

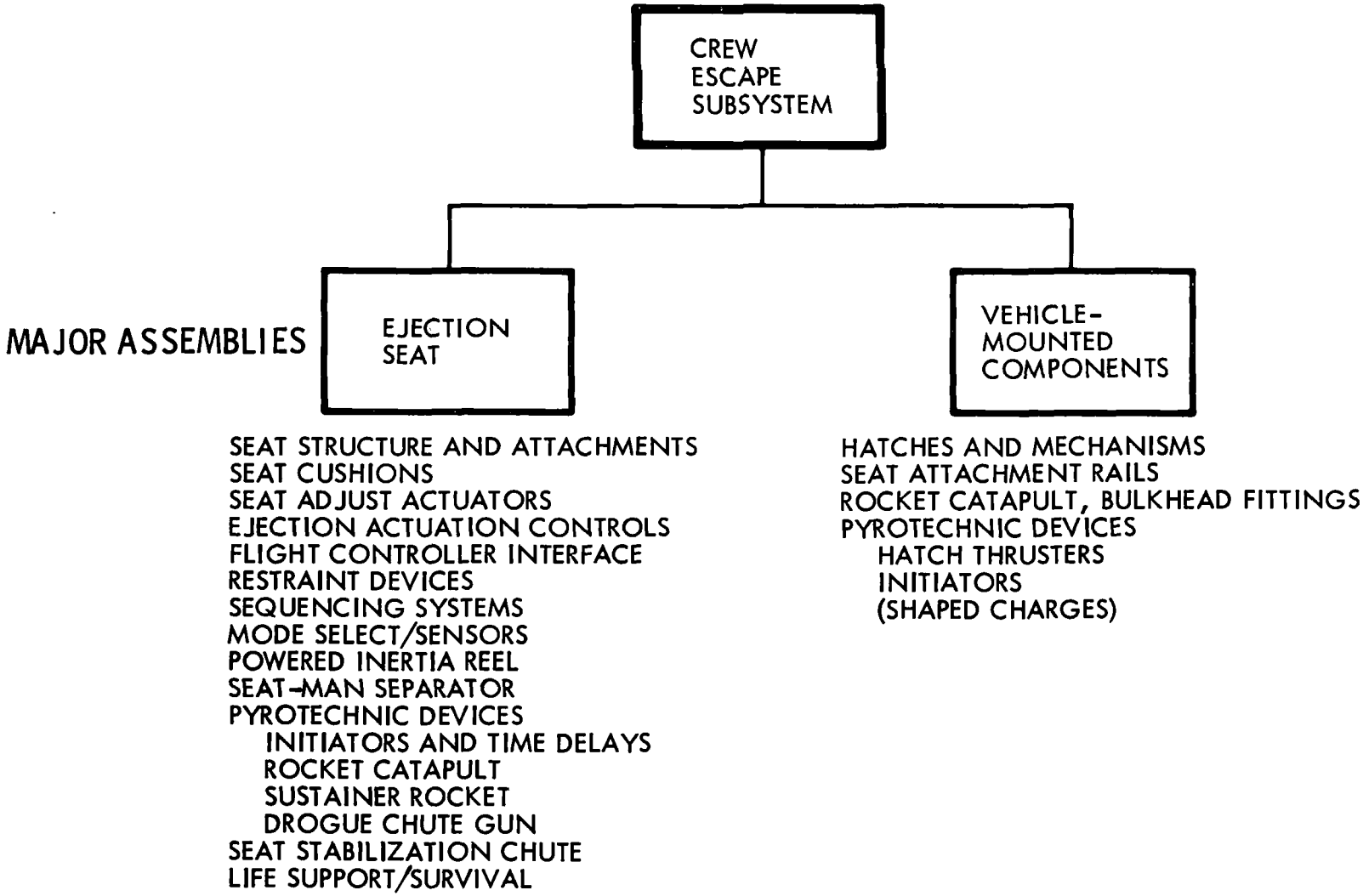


Figure 5-57. Crew Escape System Elements

Table 5-44. Crew Escape System Certification Requirements

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout*	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
1. Structural integrity of seats under specified flight (nonejection) and contingency (i.e., crash) load conditions	S		S	P					
**2. Structural integrity of seat-to-structure attachment (i.e., ejection rails) under specified flight (nonejection) and contingency (i.e., crash) load conditions	S		P	S					
3. Structural integrity of seats under all anticipated personnel ingress/egress, normal (nonemergency) operational usage, handling, and seat installation/removal load conditions	S		S	P		S	S	S	S
4. Capability of seats to withstand mission and other specified (nonejection) environments (i.e., vibration, temperature extremes, humidity, flammability of nonmetallic materials, etc.)	S		S	P				S	S
5. Functional operability of seats in normal (nonemergency) mode, in compliance with specification requirements (i.e., seat positioning throughout adjustment range, flight personnel comfort, adequacy of seat and restraint devices to provide safe and acceptable launch, in-flight, and reentry support)			S	S		S	P	S	S
**6. Suitability of flight personnel ingress/egress adequacy of external/internal visibility, and controls/displays accessibility and operability for the design percentile range of flight crew personnel	S					S	P	S	S

*High-fidelity mockup
**Combined subsystem test

Table 5-44. Crew Escape System Certification Requirements(Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
**7. Proper function and performance of all seat mechanisms and subassemblies not related to the emergency (ejection) mode when seat is integrated with vehicle				S	S	S	P		
**8. Proper operation and functioning of ejection seat and interrelated vehicle components (i.e., canopy, canopy thrusters, ejection rails) from initiation of escape system sequence through recovery of crewman (i.e., anthropomorphic dummy) (static firing test, sled test)	S		S	S	P				
**9. Functional and structural integrity of the crew escape system (ejection seat and interrelated vehicle components) under operational conditions, through full-scale static firing and dynamic tests (Static firing test, sled test)	S	S			P				
**10. Aerodynamic, mechanical, structural, propulsive, and personnel survival aspects of the crew escape system comply with applicable specification requirements (static firing tests, sled test)	S	P			P				
**11. Structural integrity of the ejection seat components and subassemblies, and interrelated vehicle components under loads imposed by ejection, windblast, and deceleration (static firing test, sled test)	S		S	P	P				
12. Functional operability of ejection seat mechanisms and subassemblies which must perform postejection functions (i.e., seat stabilization devices, disengagement of limb restraint devices, seat-occupant separation) (static firing test, sled test)	S		S	P	P				

*High-fidelity mockup
**Combined subsystem test

Table 5-44. Crew Escape System Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout*	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
**13. Capability of the escape system to effect safe crew recovery within the specified escape envelope with particular emphasis on critical portions of this escape envelope (i.e., zero-altitude, zero-velocity; near-the-pad ejection; high-altitude, high-velocity; low-altitude, high sink rate) (static firing test, sled test)	S	S			P				
14. Safe crew recovery can be effected under varying conditions of ejection, and throughout the range of crew percentiles and static center of gravity eccentricities with respect to the rocket motor effective thrust vector (static firing test, sled test)	S	P			P				
**15. Capability for sequenced crew ejection, throughout the defined escape envelope, with respect to trajectory separation, collision or entanglement of personnel with escape system components (static firing test, sled test)	S	P			P				
**16. Adequacy of lateral displacement capability of the escape system, for a zero-altitude, zero-velocity condition in a vertical orientation (static firing test)	S	P			P				
**17. Functional operability of all escape system mechanisms and pyrotechnic devices for all anticipated environmental conditions (i.e., at ambient, high, and low temperatures; following exposure to high humidity, etc.)			S	P	S				
18. Integrity of escape system pyrotechnic devices against inadvertent actuation by electromagnetic interference			S	P	S				

*High-fidelity mockup
**Combined subsystem test

Table 5-44. Crew Escape System Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout*	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
19. Escape system pyrotechnic devices and ordnance system sequencing times within specification tolerances	S		S	P	S				
20. Effects of rocket catapult and sustainer rocket thrust misalignment in relation to combined seat/occupant center of gravity (static firing test, sled test)	S	P			P				
21. Adequacy of rocket catapult and sustainer rocket performance at various ejection conditions (i.e., temperature, crew percentile, etc.) (static firing test, sled test)	S				P				
**22. Ejection accelerations, rates-of-onset, combined load factors, and rates of angular displacement are within human tolerance limitations (static firing test, sled test)	S	P			P				
**23. Adequacy of hatch separation and trajectory characteristics for both the horizontal and vertical orientations in a zero-altitude, zero-velocity mode (static firing test)	S	P		P					
24. Suitability of escape system pre-ejection sequences (i.e., packaging of seat occupant including powered retraction and torso restraint, deployment/engagement of limb restraint devices to prevent flailing, etc.) (static firing test, sled test)	S			P	S				
**25. Acceptability of postejection trajectories of seats and hatches, to preclude probability of seat-occupant collision or entanglement with jettisoned hatches and/or vehicle structure (static firing test, sled test)	S	P			S				

*High-fidelity mockup
**Combined subsystem test

Table 5-44. Crew Escape System Certification Requirements (Cont)

Certification Requirement	Certification Category								
	Analysis	Computer/Model	Component	Assembly	Subsystem	Installation Checkout	Vehicle Integration Tests	Horizontal Flight Test	Vertical Flight Test
	1	2	3	4	5	6	7	8	9
26. Aerodynamic characteristics of seat-occupant combination, and stability of seat-occupant combination in free flight (i.e., seat drogue chute stabilization characteristics, low-speed dynamic stability, and high-speed aerodynamic stability) (static firing test, sled test)	S	P			P				
27. Adequacy of postejection separation of seat and occupant, and occupant recovery characteristics (i.e., controlled positive separation, personnel parachute deployment times, probability of seat-parachute entanglement) (static firing test, sled test)	S	P			P				
28. Capability for low-altitude parachute recovery of ejected crewman (i.e., low and high speeds, minimum time from ejection initiation to recovery) (sled test)	S	P			P				
**29. Acceptability of effects on vehicle induced by ejection sequence (i.e., flight crew station noise level and pressure variations subsequent to hatch jettison, vehicle structural integrity subsequent to hatch jettison/seat ejection) (sled test)	S	S			P				

*High-fidelity mockup
**Combined subsystem test

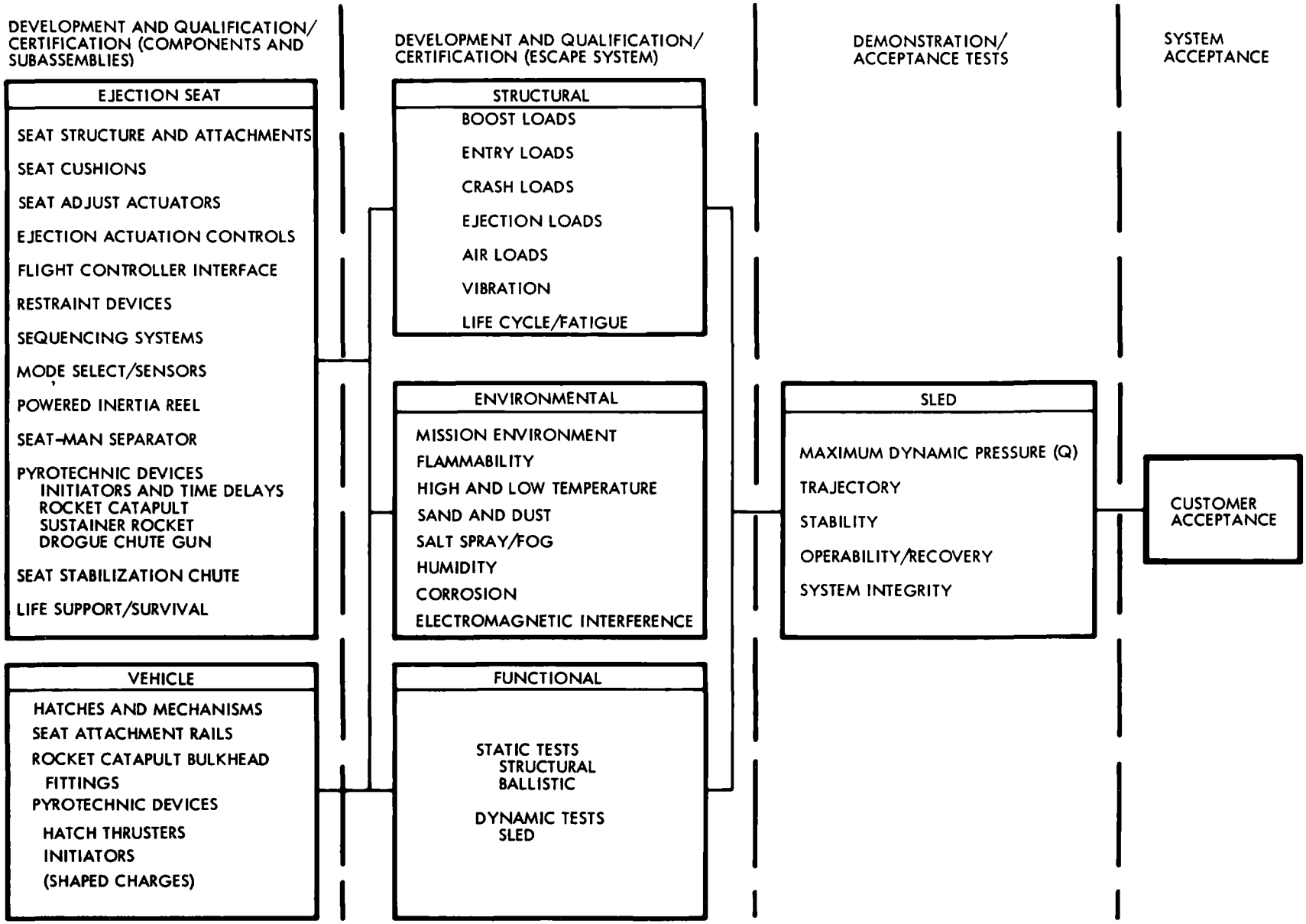


Figure 5-58. Crew Escape System Test Logic Network

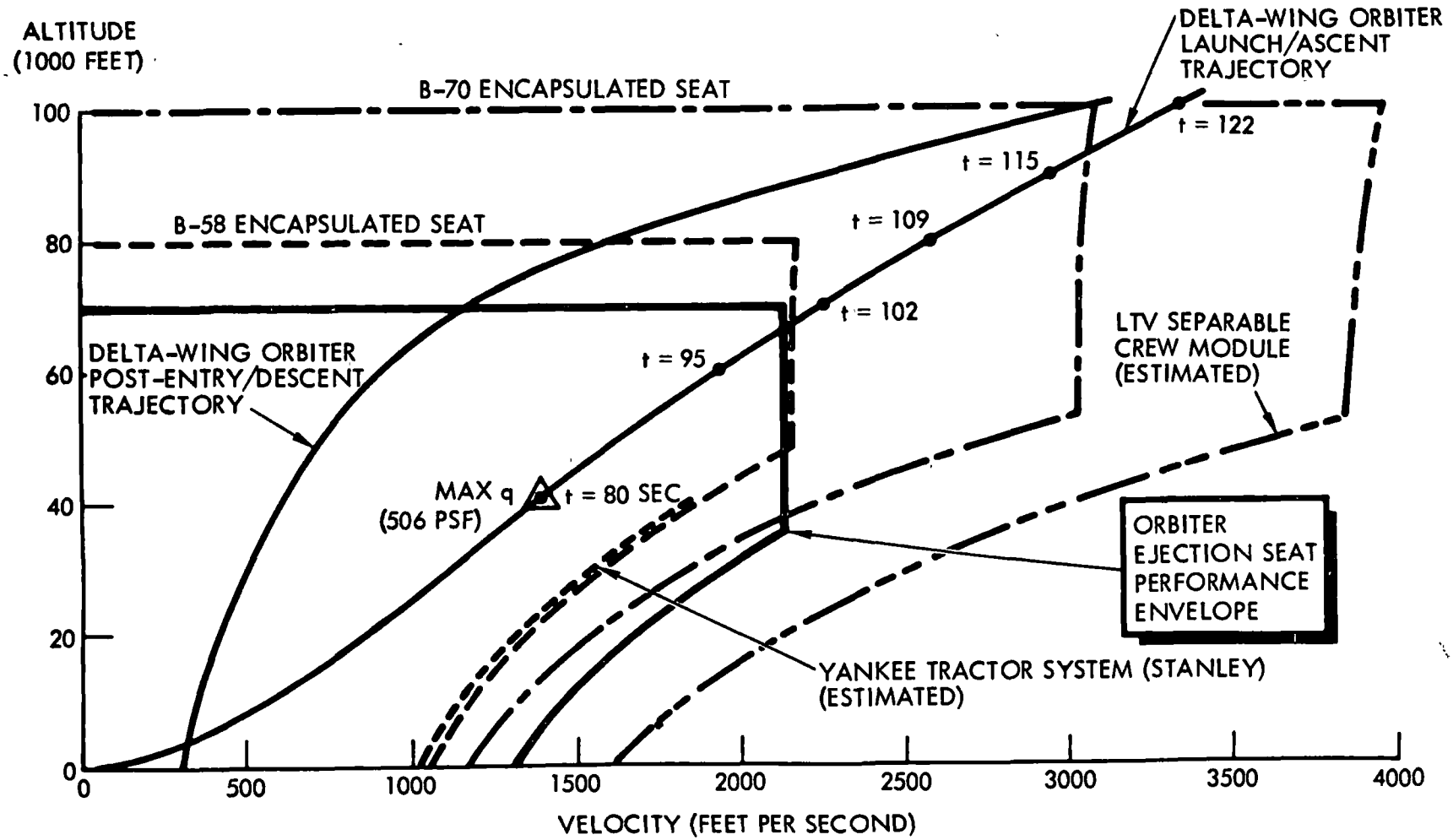


Figure 5-59. Crew Escape System Capabilities

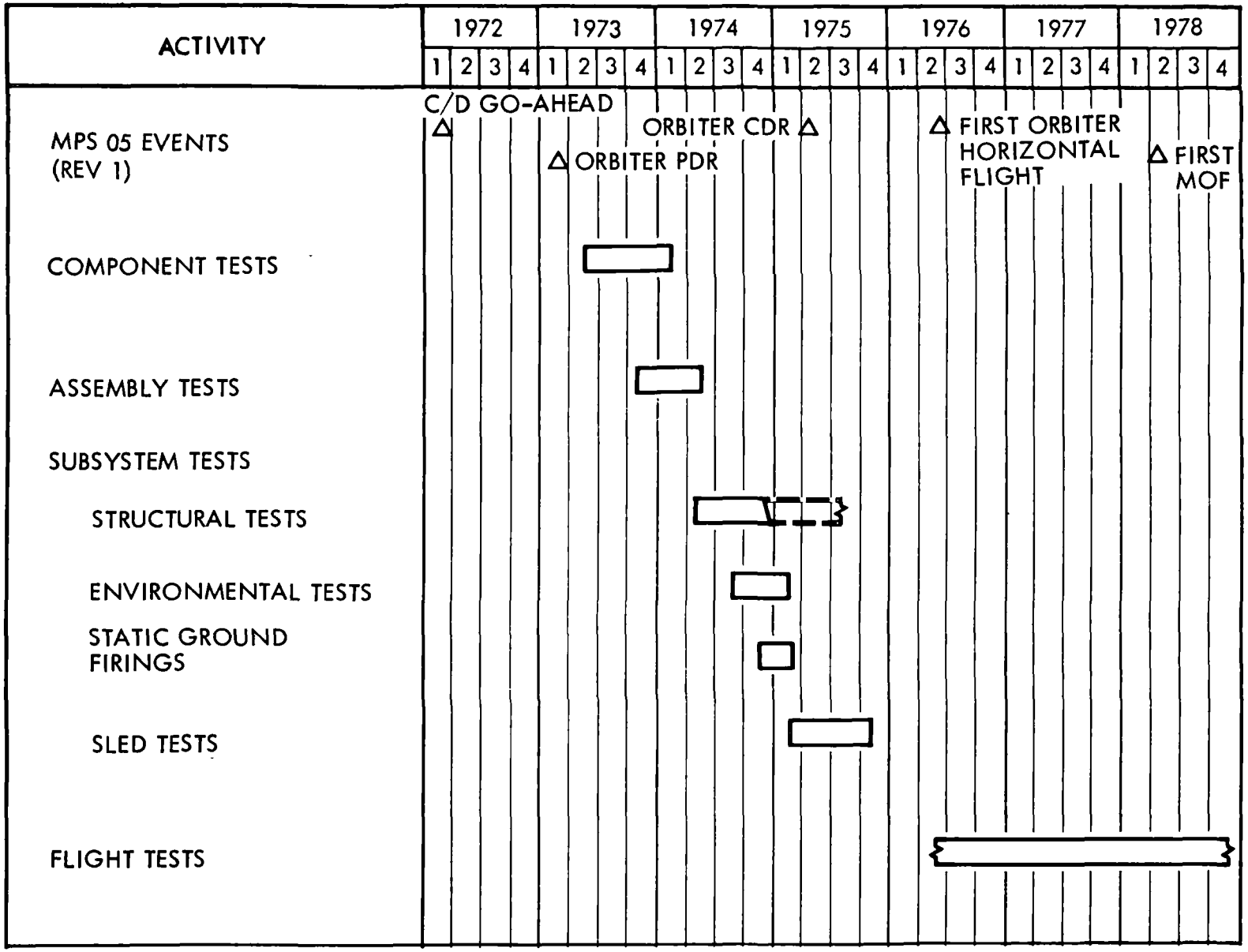


Figure 5-60. Crew Escape System Test Schedule

Table 5-45. Test Article Requirements — Crew Escape System

Assembly	Quantity		
	Structural Tests	Environmental Tests	Other Tests (Type Specified)
Ejection seats	4	2	1 (functional - retain as spare) 8 (static ground firing - horizontal and vertical) 14 (sled tests - low, intermediate, and high speeds)
Bulkhead, rails and catapult fittings	2	2	1 (functional - install in mockup) 2 (static ground firing test fixture) 2 (sled test vehicle)
Hatches and Thrusters	2	2	1 (functional - install in mockup) 4 (static ground firing - horizontal and vertical) 14 (sled tests - low, intermediate, and high speeds)

Note: The quantities shown do not include requirements for development or qualification of individual components or subassemblies.

Table 5-46. Support Requirements – Flight Personnel Provisions

Item	Requirements
Facility	Structural test laboratory Environmental test laboratory Escape system static firing test range High speed track
Support equipment	Mockups of crew and passenger compartments Structural test fixtures Static firing test stand and tower Sled test vehicle Anthropomorphic dummies High-speed and standard-speed photographic support (sled and static firing ground tests) Personnel parachutes Data acquisition system Telemetry system
Software	Miscellaneous programs for analysis of test data

5.14 BODY STRUCTURE

5.14.1 Description

The body structure consists of three major assemblies: forward body, mid-body, and aft body (Figures 5-61, 5-62, and 5-63).

The forward body structure is made up of a nose assembly, integral LH_2 tank with associated forward and aft attach skirts, and the crew cabin with IVA tunnel (Figure 5-64). The nose assembly (Figure 5-65) is of skin-stringer frame construction and includes the nose wheel compartment, drag links, trunnions, and actuators. Support structure is provided for aerodynamic, actuator, and nose wheel loads. The LH_2 tank (Figure 5-64) has integrally milled external stringer and frame attach ribs and is machine-welded to end domes and mechanically fastened to a central divider. Internal spray-on foam insulation is used on the tank walls and bulkheads. The tank supports the TPS, forming a cavity between the tank skins and outer shell. The integral tank is therefore subjected to aerodynamic and inertia loads as well as tank internal and cavity differential pressure loads. The cabin support fittings provide a determinate load path to react cabin loads. The crew cabin (Figure 5-66) is of welded skin-stringer-frame construction with pressure-sustaining internal bulkheads with airlock doors and cutouts for windows, emergency escape hatch, entrance hatch, and IVA tunnel hatch.

The mid-body structure (Figure 5-67) consists primarily of hat-stiffened skin with stability frames and major cutouts for the cargo bay and the ABES. This section contains two "floating" LO_2 tanks of waffle-grid construction and their aft skirts and forward support structure. The mid-body shell is closed out at each end with a complete bulkhead. Torsional stiffness is provided by a network of trusses which extend the entire length of the mid-body section and surround each of the LO_2 tanks. An additional bulkhead is included to provide rigidity and a load path for the wing forward spar support loads. This section also contains fittings and load diffusion structure for loads coming from the booster forward and aft attach fittings, main engine thrust structure, ABES support structure, and OMS tanks.

The aft body (Figure 5-68) is primarily the main engine compartment. The body shell is of skin-stringer frame construction and contains the main and on-orbit engine thrust structures. The ME thrust structure consists of a primary machined aluminum truss which receives the engine thrust loads and secondary trusses to distribute the primary truss loads to the main aft body structure. This section also provides the support structure for the vertical stabilizer.

5.14.2 Requirements

The structural integrity of all primary and secondary structure will be established by analysis and verified by tests under a number of selected critical load conditions. The verification requirements will include all of the requirements listed in Table 5-47.

5.14.3 Approach and Rationale

The approach to be used in the development and qualification of the body structure is presented in Figure 5-69, Test Logic and Constraint Network. Completion of all static limit load tests for conditions critical for horizontal flight is considered a constraint on horizontal flight. Completion of all ultimate load static structural qualification tests is considered a constraint on mated vertical flight. Operational certification will be constrained by satisfactory completion of all fatigue tests.

The structural testing program is arranged to provide timely information and the support required for each phase of the design, fabrication, and analysis effort from material selection, and manufacturing process optimization to final structural design verification and end product acceptance. The structural testing program will encompass the following: material process testing, structural development testing, and acceptance and qualification testing (Figure 5-69).

Material and process testing will be performed to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the structural subsystem. Areas to be investigated include the following:

1. The ability of seals, sealants, lubricants, and grease to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flamability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Compatibility of materials in contact with each other in environments that could result in degradation of properties.

4. Compatibility, stability, and thermal and physical characteristics of propellant tank insulation.

5. Reusable propellant tank thermal insulation systems (integrated into the structural environment) having the capability to minimize

propellant losses as well as moisture condensation during ground operations.

6. Effects on structure system of corrosion with regard to useful life candidate materials.

7. Optimization of special welding techniques verified by mechanical and nondestructive tests.

8. Fabrication techniques for producing extremely large, integrally reinforced and contoured tank panels and contoured "Y" rings.

9. Fracture mechanics design data to predict the critical flaw size and growth under sustained and cyclic loading for structural materials.

10. Physical and mechanical properties of shuttle structural materials which have not been established previously.

11. Joining methods for candidate alloys for shuttle structural and thermal requirements.

12. Demonstrate thermal performance, structural integrity, materials compatibility, and reusability of orbit maneuvering cryogenic tank insulation.

13. Development of materials accelerated life-test methods.

14. Development of composite materials technology (process development and property determination, forming, joining, etc.) to achieve significant structural weight savings.

Structural development testing will be performed early in the program to provide test data on critical or difficult to analyze areas. This will provide knowledge of internal load distribution in areas of configuration complexity, load path redundancy, or high load dissipation. This early testing will aid in minimizing weight and reduce the risk of premature failure of the major structural test articles. Major development test areas include:

1. Booster attach fittings and load diffusion structure.

2. Wing and vertical stabilizer carrythrough or support structure.

3. LH_2 tank aft skirt to mid-body transition structure.

4. Main engine thrust structure to mid-body transition structure.

5. LO_2 tank aft skirt structure.

6. TPS support structure.

7. Cargo bay doors.

Acceptance testing, primarily of the pressurized structure, is designed to demonstrate the flightworthiness of each delivered article. By pressurizing the structure sufficiently in excess of the maximum design pressure, the test and subsequent nondestructive inspection will give the required high confidence in the ability of the structure to undergo the required life spectrum loading without compromise to mission requirements.

Acceptance testing will include the following:

1. Pneumostatic proof-test of the crew compartment cabin at room temperature prior to systems installation to demonstrate structural integrity. Cabin leak rate will be checked at this time and just prior to crew compartment mate in final assembly.

2. Hydrostatic proof-test of the LH_2 tank bulkheads, plus pneumostatic proof-testing of the complete tank and skirt assembly (at room temperature), followed by a leak check. Pressures will be adjusted for material property differences between test and operational temperatures.

3. Hydrostatic proof-test of the LO_2 tank bulkheads, plus hydrostatic proof-testing of the complete tank and skirt assembly. High-density spheres will be added to the water so that the total test pressure gradient simulates orbital flight pressure (ullage plus 3g LO_2 head, adjusted for material property differences between test and flight temperatures).

Acceptance test requirements are summarized in Table 5-48.

Qualification testing will demonstrate the vehicle structural integrity and compliance with design criteria by testing to design limit and ultimate loads for the most critical load and environmental conditions. "Safe-life" capability will be certified by subjecting the structure to four complete life spectrum loadings (400 flights).

The sequence of testing and the selection of test article configuration is designed to gain the most critical information as soon as possible while attempting to minimize program risk and testing costs.

It is highly desirable that the main propellant tank be tested in the vertical position to facilitate close simulation of propellant acceleration forces. Other prime requirements are that the test article maintain structural continuity in the region of the booster attach fittings, the wing carrythrough structure, and the vertical stabilizer attach structure in order to adequately duplicate load diffusion characteristics in these highly loaded local areas. Based on these requirements, it is planned to test the entire body section with aerodynamic surfaces attached in a horizontal altitude and subsequently conduct the LH_2 and LO_2 tank structure tests in a vertical attitude.

The basic test articles required to qualify the body structure, as defined in Figures 5-62 and 5-63 and in Table 5-47, are as follows:

1. Cabin: one test article will be used to qualify the cabin and cockpit control system for static and fatigue loads.

2. Complete body with aerodynamic surfaces: one static article and one fatigue article will be used to qualify the body structure. For static and fatigue load tests, each will include the wing and vertical stabilizer attachments, NLG support structure, engine thrust support structure, tank support structure, major doors and door support structure.

3. LH_2 tank and tank skirt structure: one static article and one fatigue test article (removed from the complete static and fatigue body sections described above) will be used to qualify the basic tank and the forward and aft tank skirt structure for critical static and fatigue loads.

4. LO_2 tank, aft tank skirt, and forward attachment structure: two forward LO_2 tank bulkheads and attached partial tank body sections and two aft LO_2 tank bulkheads with their aft skirt structure and attached partial tank body sections will be used to qualify the LO_2 tank structure for critical static and fatigue loads.

The use of a single crew cabin, separate from the main body, is considered a reasonable, cost-effective approach for both static and fatigue testing since the body reaction loads are statically determinate and the cabin is primarily designed by internal pressure. Critical features of the cabin design, such as bulkheads and cutouts for the windows and hatches (docking, tunnel, etc.), will be thoroughly tested at the structural element component level. Static limit-load tests for the cabin critical design conditions will be conducted before initiation of the fatigue test program. During the fatigue test program, the cabin will be subjected to pressure cycling,

inertia loads, and external aerodynamic loads for an equivalent lifetime of 400 flights. The cabin will then be subjected to 1.1 times the critical design limit loads with minimum limit internal pressure followed by critical limit loads combined with 1.3 times the maximum limit internal pressure. Leakage rates will be monitored at appropriate intervals. All cabin tests will be conducted with the TPS panels removed. Both the static and fatigue cabin tests will be conducted at room temperature since the temperature of cabin load-carrying structure is not expected to exceed 120 F.

The complete body static test article will first be loaded at selected points on the body, thrust structure, and attached aerodynamic surfaces to provide influence coefficient data for verification of analytical stiffness matrices utilized in the dynamic modal analyses. In addition, loads will also be applied to the LO_2 tank forward and aft attachment points on the body structure to verify analytical influence coefficients used in the calculation of the redundant LO_2 tank to tank support loads to be applied in later tests.

Static limit and ultimate load tests will be conducted for critical design conditions such as boost, maximum q, maneuvering, and landing loads. The forward body LH_2 tank will be pressurized with GN_2 (utilizing volume displacement devices to minimize stored energy) to limit design pressure during application of forward body loads to qualify the forward LH_2 tank skirt and body structure aft of the LH_2 tank. Applied body loads will be reacted by loads on the wings (see Section 5.15), booster attachment fittings, or landing gear attachment structure, as appropriate. In those local areas where combined loads and thermal environment are considered critical, the appropriate surface temperature versus time profile will be simulated while the static limit and ultimate loadings are held.

After completion of the body static ultimate tests, the forward fuselage containing the LH_2 tank and skirt structure will be mounted vertically in a test tower on a stub simulated mid-body section. The tank will be tested for critical limit and ultimate body loads with minimum-limit internal pressure followed by limit body loads with maximum ultimate internal pressure. Limit and ultimate tank sidewall and bulkhead pressures will be achieved by using LN_2 and volume displacement spheres of a density required to duplicate flight inertia loads.

Upon receipt, the forward fuselage fatigue test article will be installed in the same vertical test tower utilized for the static test. The fatigue test program will consist of the application of spectrum load levels and pressure cycling (ullage plus head) of the LH_2 tank to an equivalent lifetime of 400 flights for critical design conditions. The LH_2 tank will be partially filled with LN_2 and low-density volume displacement spheres, and pressurized with GN_2. The tank insulation will be reduced or omitted to permit achievement of thermal cyclic temperatures. During this phase of testing

a GN_2 external purge will be used to inhibit moisture accumulation. External heaters will be used to heat the tank structure to achieve the high-temperature portions of the thermal profile (approximately 300 F on the external tank structure). Loads, pressures, and thermal environment will be programmed in real time, where required, and time will be compressed where adequate simulation can be accomplished.

After completion of the forward body-LH_2 tank fatigue test, the forward body will be mated to the mid- and aft body sections for the complete body fatigue test. The complete-body fatigue test will be conducted in a manner similar to the static test using the same test fixtures. Fatigue loads will be applied to spectrum load, pressure, and temperature levels to an equivalent lifetime of 400 flight for the critical design conditions. Again, real-time programming and time-compression programming of test parameters will be utilized, as appropriate.

The LO_2 tank qualification tests will be performed on two forward bulkheads, each attached to a representative length of sidewall, and two aft bulkheads, each attached to their skirt structure and a representative length of sidewall. Each of the two types of test specimens will be mounted in a vertical test fixture and sequentially tested for static limit and ultimate loads on one specimen and to an equivalent fatigue life test of 400 flights on the second specimen. The static tests will consist of critical static limit and ultimate loads combined with limit internal (ullage plus head) tank pressure followed by application of limit load and ultimate (ullage plus head) tank pressure as in previous pressure tests. The fatigue tests will be conducted in a manner similar to those previously discussed. The tank pressures for both the fatigue and static tests will be applied utilizing LN_2 and high-density spheres to simulate inertia loads. Since the LO_2 tank is not insulated, it is planned to have a continuous GN_2 purge adjacent to the tank to preclude excessive accumulation of moisture.

Precision deflection devices will be used for measuring deflections at selected locations during the body-influence coefficient tests and all body or tank static tests. Strain gauge and pressure measurements will be recorded as required on all static and fatigue tests. During the course of each test program, appropriate visual and NDT inspection techniques will be employed periodically to inspect for structural damage.

The body structure test logic and constraint network is shown in Figure 5-69, and the body test schedule is presented in Figure 5-70.

5.14.4 Test Article Requirements

Test article requirements are summarized in Table 5-48.

5.14.5 Support Requirements.

Table 5-49 presents the support requirements.

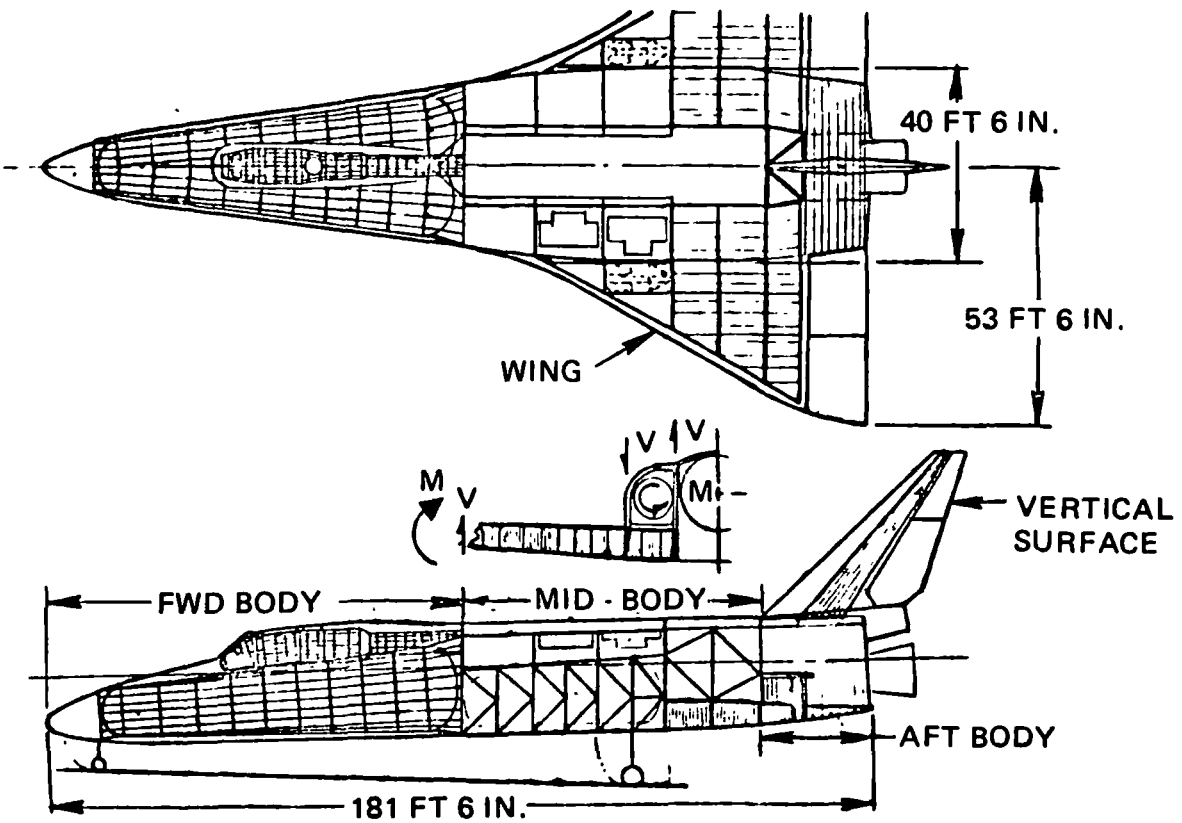


Figure 5-61. Delta-Wing Orbiter Structural Arrangement

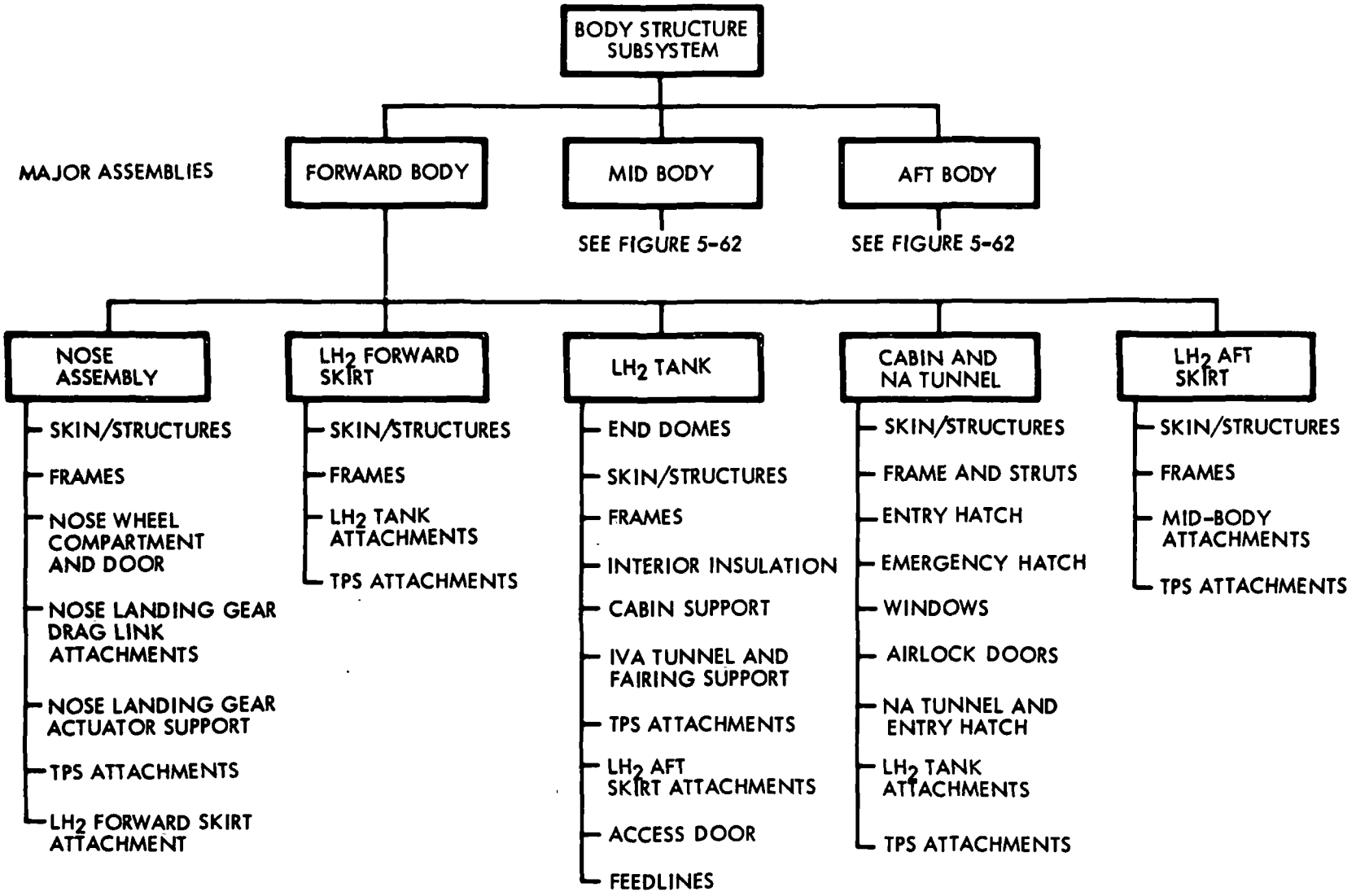


Figure 5-62. Body Structure Elements

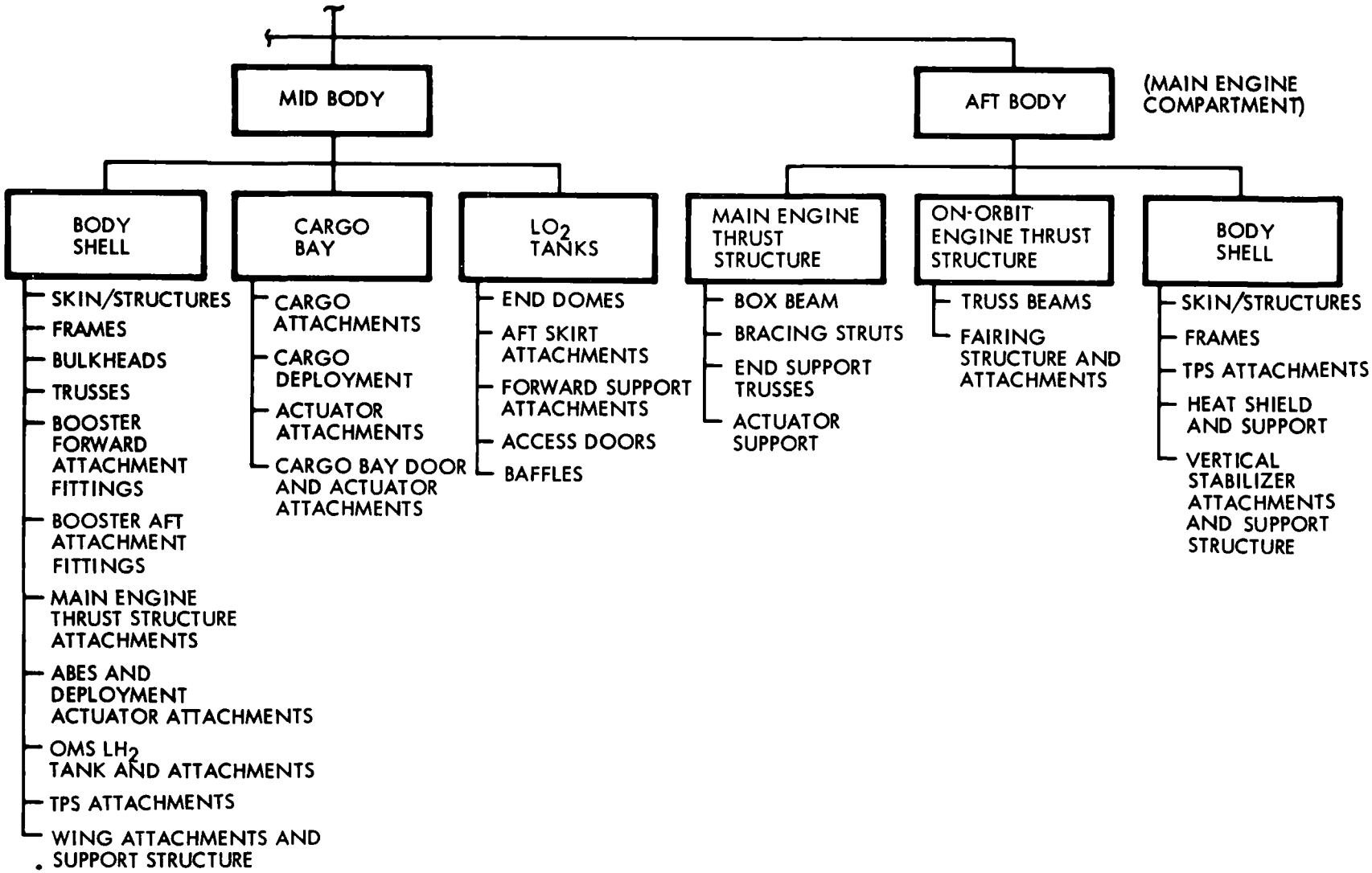


Figure 5-63. Mid-Body Structure Elements

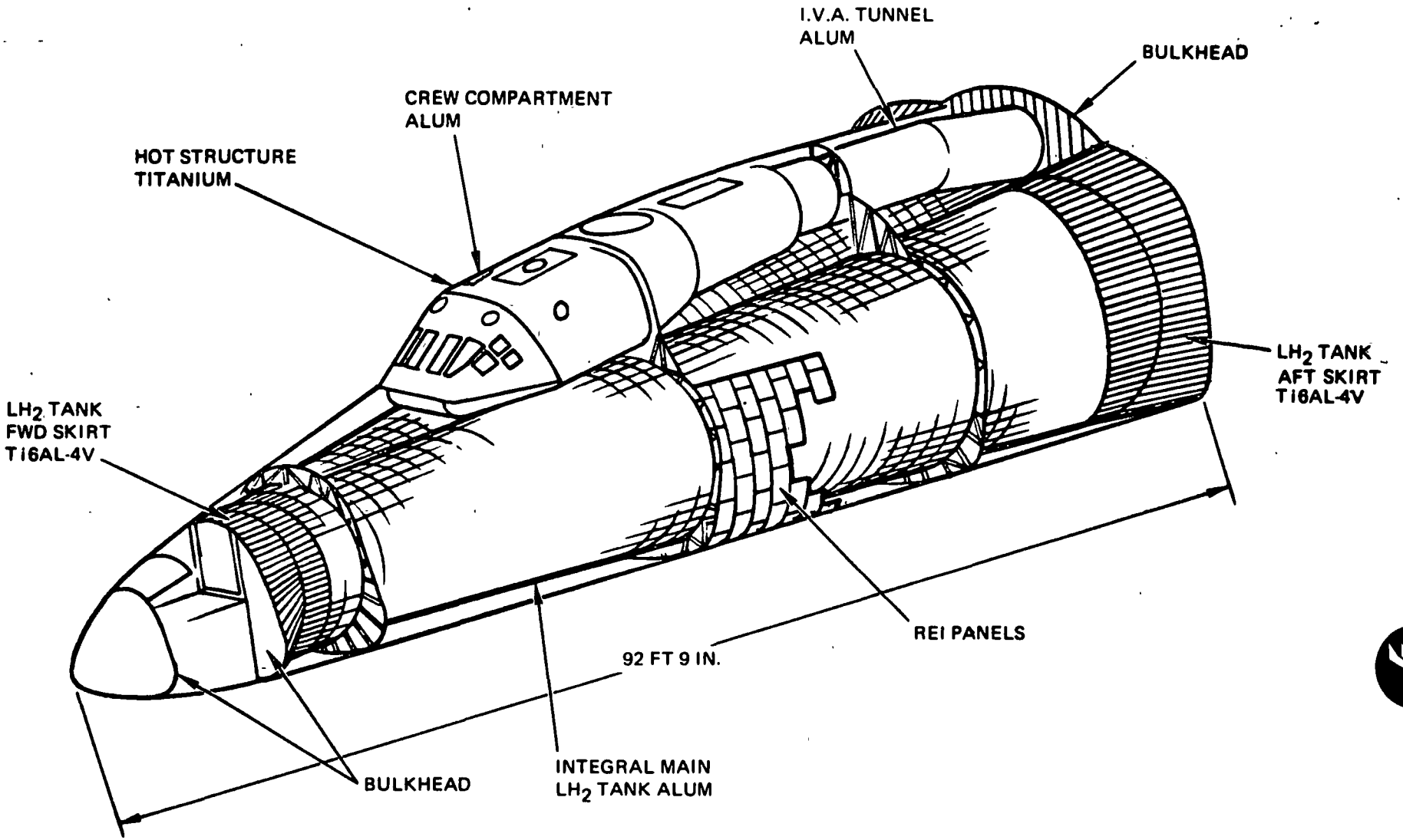


Figure 5-64. Forward Body Section

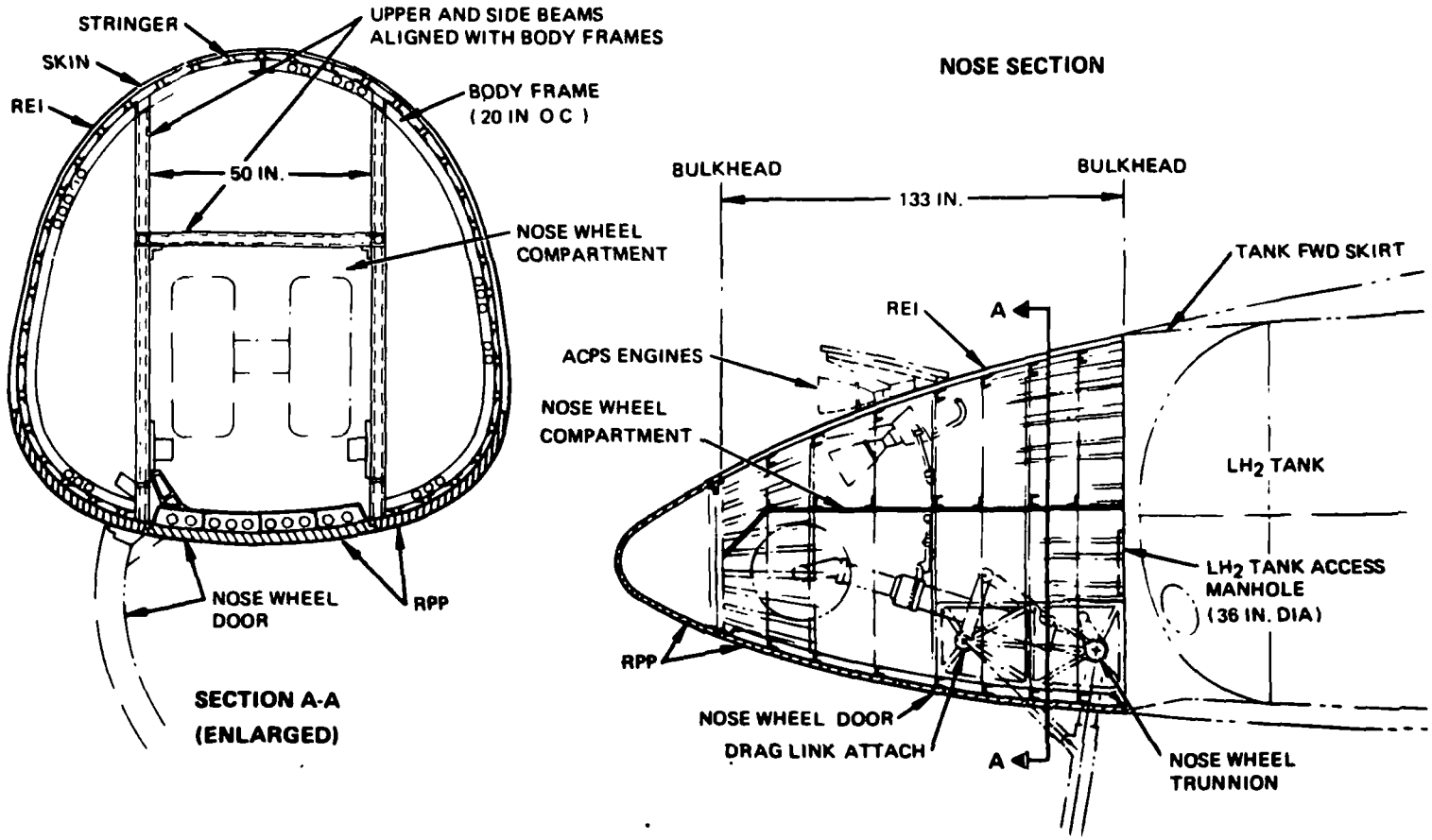


Figure 5-65. Nose Wheel Compartment Titanium Structure

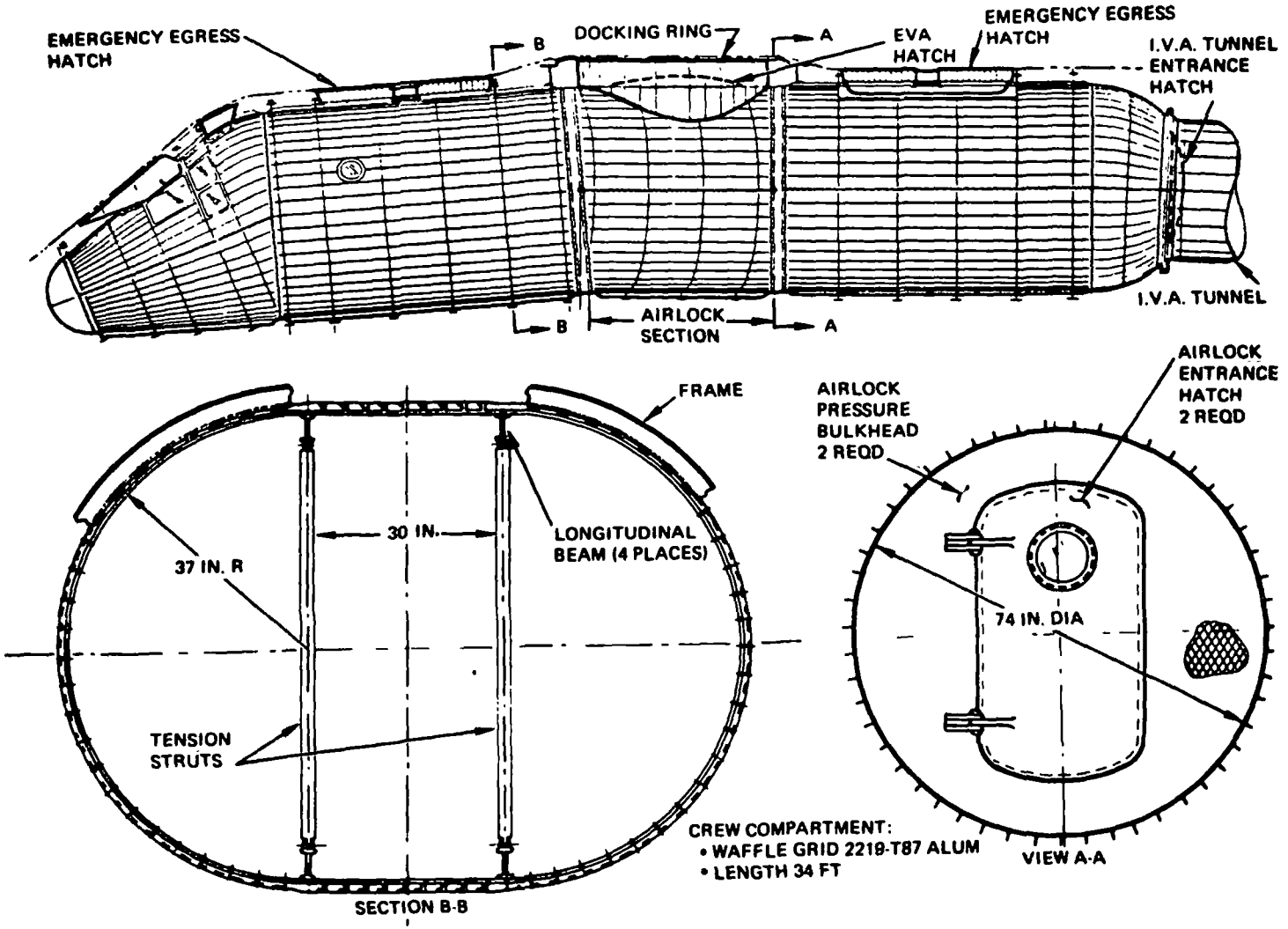


Figure 5-66. Crew Compartment Key Structure

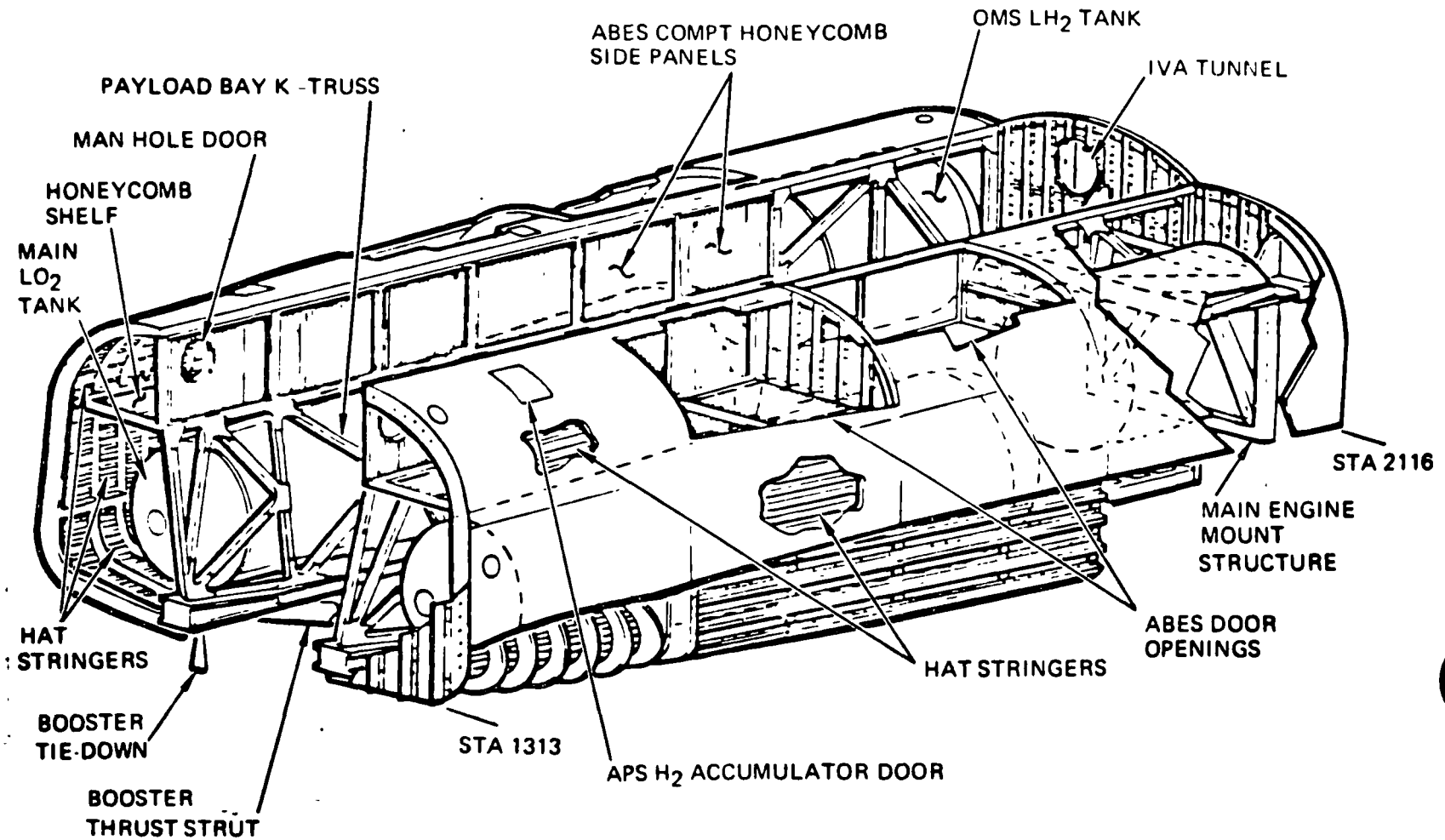


Figure 5-67. Mid-Body Section

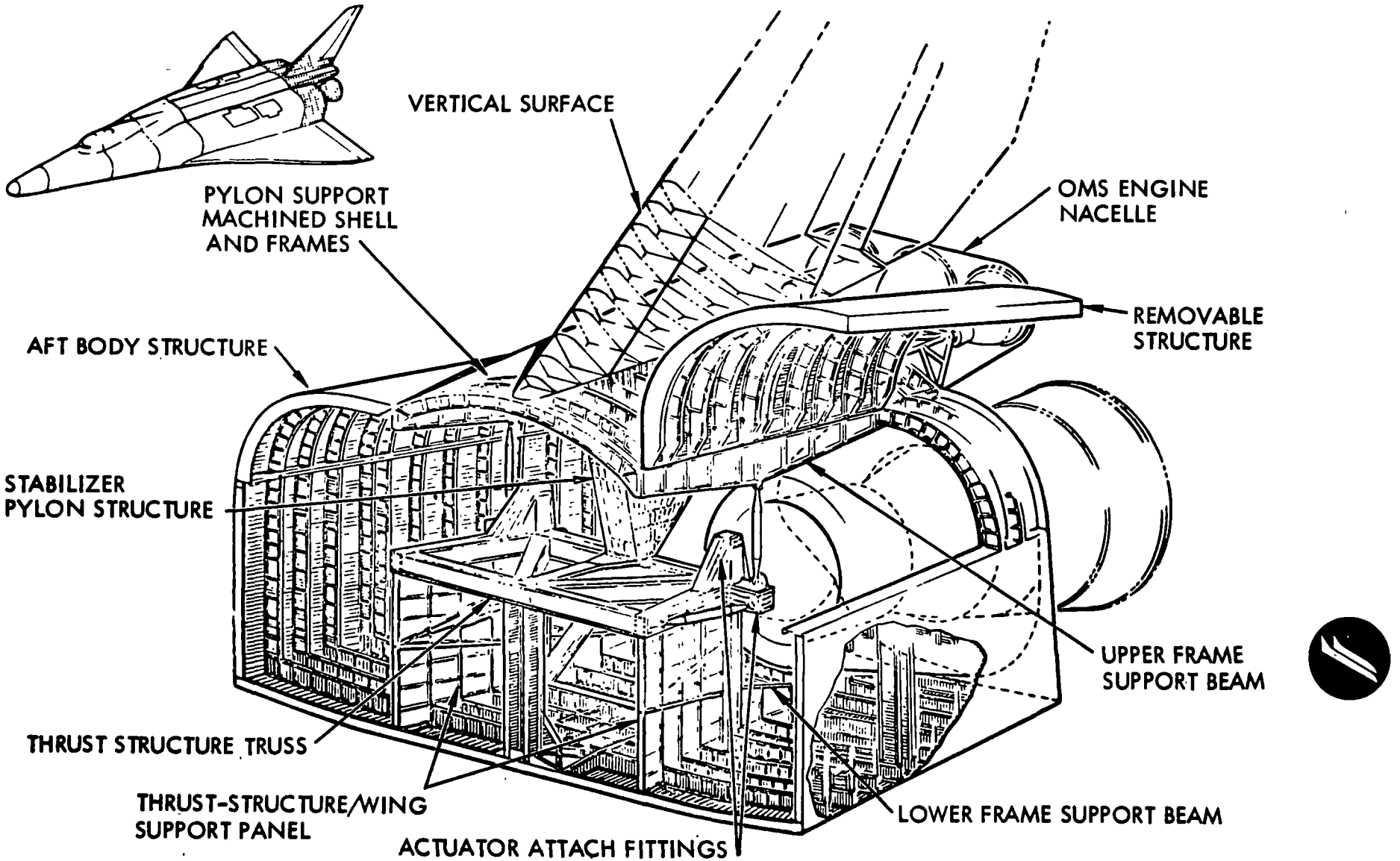


Figure 5-68. Main Engine Compartment

Table 5-47. Body Structure Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL TEST REQUIREMENTS *							
1. Ability of the structure to sustain design (limit) loads with no detrimental deformation.					P		
2. Ability of the pressure vessel structure to sustain 1.10 X design loads without yielding (0.2% offset).					P		
3. Ability of the structure to sustain ultimate loads (design loads X. F. S.) without rupture or collapse.					P		
4. Ability of the structure to sustain four complete life spectrum loadings (400 flights).					P		
5. Adequacy of inspection techniques to detect critical defects within the inspection interval established in the fracture control plan (for structures that depend on nondestructive inspection for "safe-life" assurance).					P		
6. "Fail-safe" capability for structures incorporating this philosophy in their design of "safe life" inspection interval.					P		
7. Ability of the structure to withstand dynamic effects without impairing structural or functional adequacy.						P	
8. Functional adequacy of all mechanical component support structure after complete life spectrum load history.					P		
9. Extensional, shear, rotational, and bending stiffnesses of entire body structure.					P		
* Items 1 through 8 are to be verified under true or simulated environmental effects, where applicable (cryogenic or heat).							
FORWARD BODY SECTION							
1. Structural integrity of the forward landing gear support structure under taxi and landing loads.					P		

Table 5-47. Body Structure Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
2. Structural integrity of the nose wheel compartment under aerodynamic and inertia loads under design thermal environment.					P		
3. Structural integrity of the LH_2 tank with forward and aft skirts under critical aerodynamic, inertial, TPS, and internal pressure loads.					P		
4. Ability of the LH_2 tank to sustain four complete life spectrum loadings (400 flights).				P			
5. Ability of the LH_2 tank and body structure to take purge gas pressure loads.				P			
6. Structural integrity of the crew cabin and IVA tunnel support structure.					P		
7. Structural integrity of the crew cabin and IVA tunnel under aerodynamic, inertial, and internal pressure loads and thermal environment.				P			
8. Ability of the crew cabin to sustain four complete life spectrum loadings (400 flights).				P			
9. Ability of windshield and adjacent structure to withstand impact loads.				P			
10. Ability of crew cabin to withstand emergency escape docking loads.				P			
MID-BODY SECTION							
1. Spring constants and structural integrity of the wing attach area.				S	P		
2. Spring constants and structural integrity of the booster attach fittings and adjacent areas.					P		

Table 5-47. Body Structure Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
3. Spring constants and structural integrity of the thrust structure attach area.					P		
4. Structural integrity of the aft portion of the LO_2 tank, LO_2 aft skirts, and adjacent structure under tank internal pressure, inertial loads, and cryogenic environment.				P	S		
5. Ability of the LO_2 tank to sustain four complete life spectrum loadings (400 flights).				P			
6. Structural integrity of the forward portion of the LO_2 tank and support structure				P			
7. Structural integrity of the cargo pod attach structure.					P		
8. Structural integrity of the ABES and OMS LH_2 tank support structures.					P		
AFT-BODY SECTION							
1. Spring constants and structural integrity of the main engine thrust structure and support area.					P		
2. Spring constants and structural integrity of the vertical surface attach area.				S	P		
3. Structural integrity of the on-orbit engines thrust structure and attach area.					P		
4. Structural integrity of the ME heat shield under pressure and thermal environment.				P			
5. Ability of the ME thrust structure to sustain four complete life spectrum loadings (400 flights).					P		

Table 5-47. Body Structure Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
IN PROCESS CHECKOUT REQUIREMENT							
1. Crew compartment proof test and leak rate check.				P			
2. LH_2 tank bulkheads hydrostatic proof tests.			P				
3. LH_2 tank and skirt assembly proof-test (pneumostatic) and leak check.				P			
4. LO_2 tank bulkheads hydrostatic proof test.			P				
5. LO_2 tank and skirt assembly proof test hydrostatically (with high-density spheres).				P			

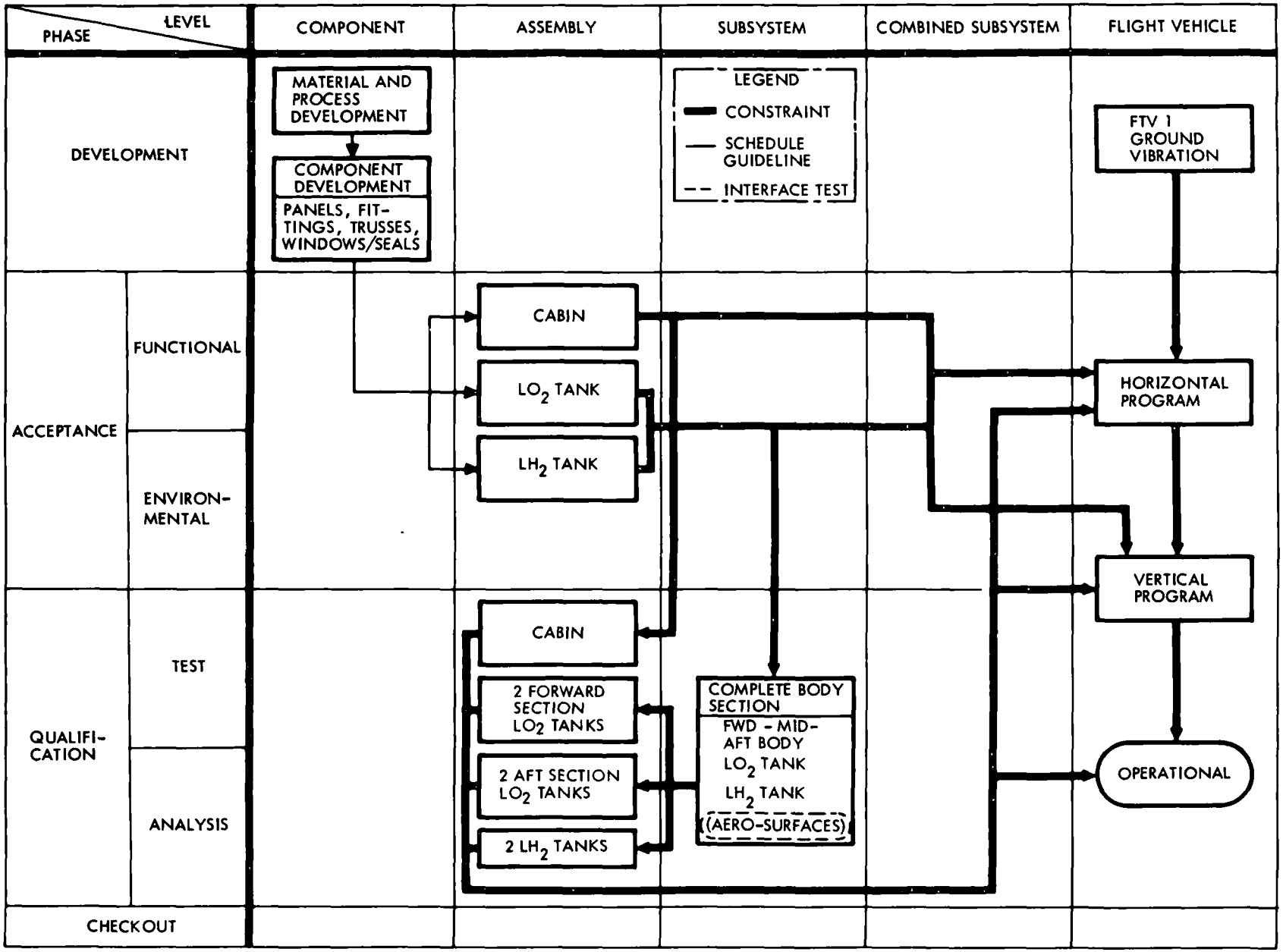


Figure 5-69. Body Structure Test Logic Constraint Network

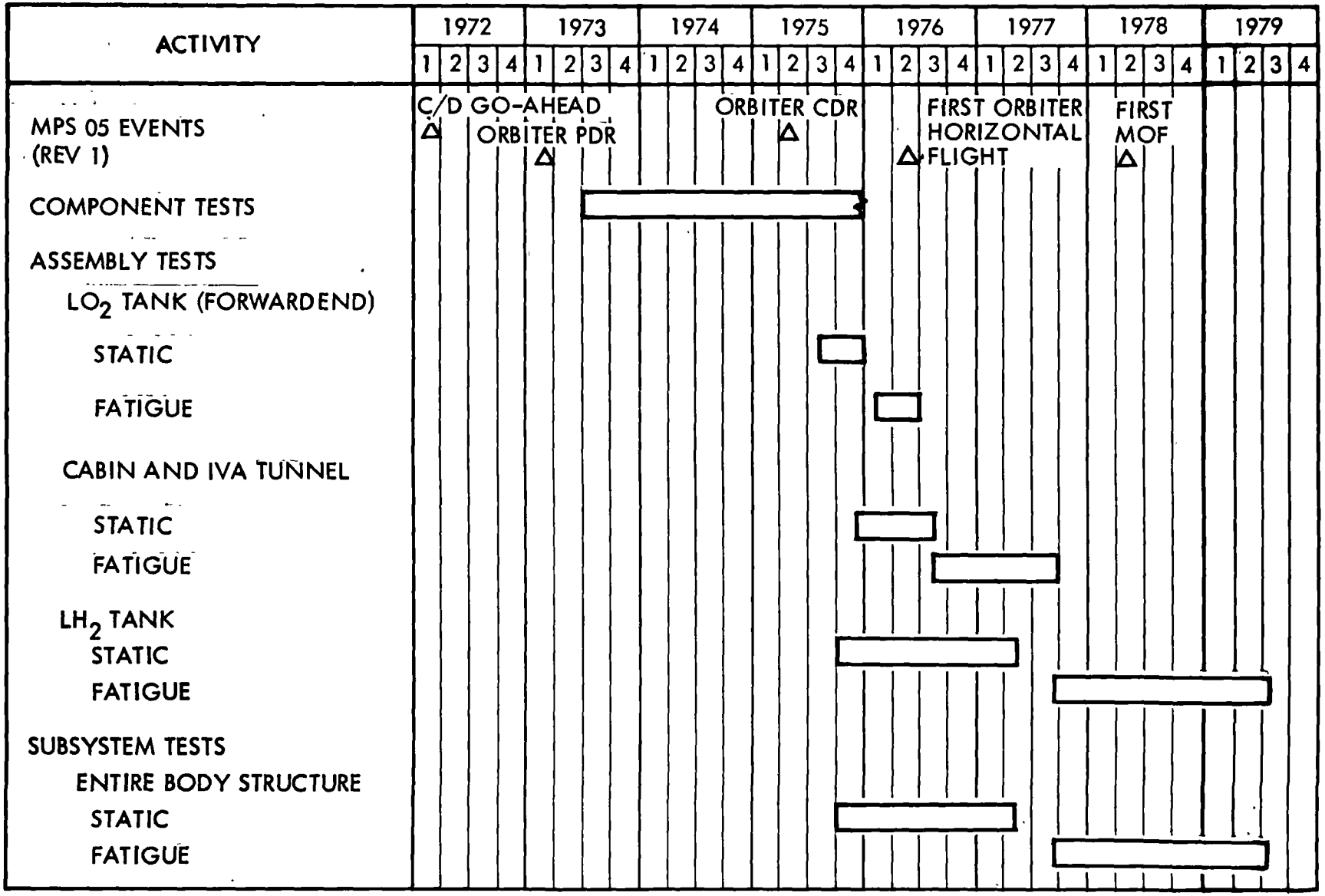


Figure 5-70. Body Structure Test Schedule

Table 4-48. Body Structure Subsystem Test Article Requirements

Item	Test Article Description	Type of Test	Quantity
A	Crew cabin, including cockpit controls, seat backup structure, windows, hatches, and IVA tunnel.	Qualification, static and fatigue	1
B	Forward body section, including nose section, NLG support structure, NLG doors, and LH_2 tank and skirt structure (less crew cabin and IVA tunnel and NLG)	Qualification, static ultimate and fatigue	1.8
C	Mid-aft body section, including cargo bay doors and supporting structure, OMS and ME thrust structure, and wing and vertical stabilizer attachment structure.	Qualification, static and fatigue	2
D	LO_2 aft skirt, LO_2 aft bulkhead, and approximately 6 feet of adjoining conical tank sidewall plus a closeout and end-loading fixture.	Qualification, static and fatigue	2
E	LO_2 aft skirt and attachment structure	Qualification, static and fatigue	2
F	LO_2 forward bulkhead and approximately six feet of adjoining conical tank sidewall	Qualification, static and fatigue	2
G	Typical TPS panels	Qualification, static, and fatigue	3 percent

Note: The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.

Table 5-49. Body Structure Subsystem Test Support Requirements

Item	Requirements			
Facilities	1. Covered test area*	Length (ft)	Width (ft)	Height (ft)
	a. Overall body (with wing and vertical stabilizer)	210	110	75
	b. Forward body (LH_2 tank)	30	40	120
	c. LO_2 tank forward bulkhead	20	20	20
	d. LO_2 tank aft bulkhead	20	20	20
	e. Cabin	75	30	25
	2. Hydraulic power	gpm at 5000 psi		
	a. Overall body		100	
	b. Forward body		80	
	c. LO_2 tank-forward		20	
	d. LO_2 tank-aft		20	
	e. Cabin		40	
	3. Electrical power	kva at 440 to 660 vac		
	a. Overall body		4000	
	b. Forward body		4000	
	4. Cryogenic facilities. Storage and transfer facilities for 50,000-gal LN_2			
Support equipment	1. Load programmers	Program Channels	Servo Channels	
	a. Overall body	4	40	
	b. Forward body	3	20	
	c. LO_2 tank-forward	2	10	
	d. LO_2 tank-aft	2	10	
	e. Cabin	1	10	
	2. Heat programmers			
	a. Overall body	6	24	
	b. Forward body	4	18	

*assume static and fatigue tests conducted in same test fixtures.

Table 5-49. Body Structure Subsystem Test Support Requirements (Cont)

Item	Requirements	
	3. Data acquisition	Channels
	a. Overall body	1600
	b. Forward body	600
	c. LO_2 tank-forward	150
	d. LO_2 tank-aft	150
	e. Cabin	200
Software	Programming as required for heating control, load control, data acquisition, and processing.	

5.15 AERODYNAMIC SURFACES

5.15.1 Description

The orbiter aerodynamic surface consists of a delta wing and vertical surface (Figures 5-71, 5-72, and 5-73).

The wing consists of a leading edge assembly, main box section, and elevons. The leading edge consists of a nose section and rib truss-supported skin-stringers. The section forward of the main wing box contains the main landing gear wall and support structure. The main box is of multispar, rib-skin stringer construction and contains the elevon actuators and support structure. The wing trailing edge (dual elevons) consists of truss-supported sandwich skins. The vertical surface consists of a spar-rib, skin-stringer fin containing the rudder actuators and support structure. The rudders are of rib-skin-stringer construction and are designed to assist in braking.

5.15.2 Requirements

The structural integrity of the aerodynamic surfaces and main landing gear support structure will be established by analysis and will be verified by tests under a number of selected critical load conditions. The certification requirements will include all of the requirements listed in Table 5-50.

5.15.3 Approach and Rationale

The structural testing program is arranged to provide timely information and the support required for each phase of the design, fabrication, and analysis effort from material selection, and manufacturing process optimization to final structural design verification and end product acceptance. The structural testing program will encompass material and process testing, structural development testing, and qualification testing (Figure 5-74).

Material and process testing will be performed to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the structural subsystem. Areas to be investigated include the following:

1. The ability of seals, sealants, lubricants, and grease to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flamability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Compatiblity of materials in contact with each other in environments that could result in degradation of properties.

4. Effects on structure system of corrosion with regard to useful life candidate materials.

5. Optimization of special welding techniques verified by mechanical and nondestructive tests.

6. Fabrication techniques for producing extremely large, integrally reinforced and contoured tank panels and contoured "Y" rings.

7. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

8. Physical and mechanical properties of shuttle materials which have not been established previously.

9. Joining methods for candidate alloys for shuttle structural and thermal requirements.

10. Development of materials accelerated life-test methods.

11. Development of composite materials technology (process development and property determination, forming, joining. etc.) to achieve significant structural weight savings.

Structural development testing will be performed to provide test data on critical areas or areas difficult to analyze early in the program. This will provide knowledge of internal load distribution in areas of configuration complexity, load path redundancy, or high load dissipation. This early testing will aid in minimizing weight and will reduce the risk of premature failure of the major structural test articles. Major development test areas include wing box section, wing and vertical stabilizer leading edge section, rudder and elevon sections, and critical attachment fittings.

Prior to initiation of the qualification test program, influence coefficient tests will be conducted on both the wing and vertical stabilizer. This will verify the analytical stiffness matrixes previously used in dynamic modal analyses, as discussed in Section 6.8.

Qualification testing of the aerodynamic surfaces will certify their structural integrity by static and fatigue tests on separate pieces of hardware. Due to the nature of their redundant carrythrough structure, both the vertical stabilizer and the selected right or left half-wing will be tested

while attached to the static and fatigue test articles, respectively. Each of these test articles will be representative of a complete vehicle with a minimum of simulated structure.

One complete vertical stabilizer and rudder will be tested for their critical limit and ultimate loads and thermal environment conditions, with applied loads reacted by restraining loads and fixed, statically determinate reactions on the body structure. Similarly, one complete half-wing and elevon will be tested for their critical limit and ultimate loads and thermal environment conditions, with applied loads reacted by restraining loads and statically determinate reactions on the body structure and an opposing dummy wing stub fixture. The static test sequence for these proposed thermo-structural tests will require the initial application of static load to a prescribed load level followed by a complete programmed real-time thermal cycle, while holding static load. This procedure will be repeated in increments as the static load is increased to design limit and ultimate loads.

For the fatigue test program, another complete vertical stabilizer, rudder, complete half wing, and elevon will be mounted on the fatigue body section. Loads will be applied and reacted in the same manner as in the static test program, except that the loads and thermal profiles will both be programmed in a combined real and compressed time profile to produce correct thermal stresses, and combined thermal/external force induced stresses, for the equivalent of four complete loading spectrums (400 flights).

Precision deflection measurements will be made during the proposed influence coefficient and static structural tests. Strain gages will be utilized extensively for local strain measurement during both the static and fatigue qualification test programs. At appropriate intervals in both the static and fatigue test programs, thorough inspections will be performed on the critical areas of structure under test, utilizing NDT and visual inspection techniques.

Both development and qualification sonic fatigue tests will be conducted on critical panels with realistic simulation of edge restraints and internal cavities. These tests will be conducted with appropriate simulation of critical thermal environments as required.

Table 5-50 summarizes the aerodynamic surfaces certification requirements.

5.15.4 Test Article Requirements

Table 5-51 presents the test hardware requirements summary.

5.15.5 Support Requirements

Table 5-52 reflects the test support requirements. Figures 5-74 and 5-75 show the test logic and constraint network and the test schedules, respectively.

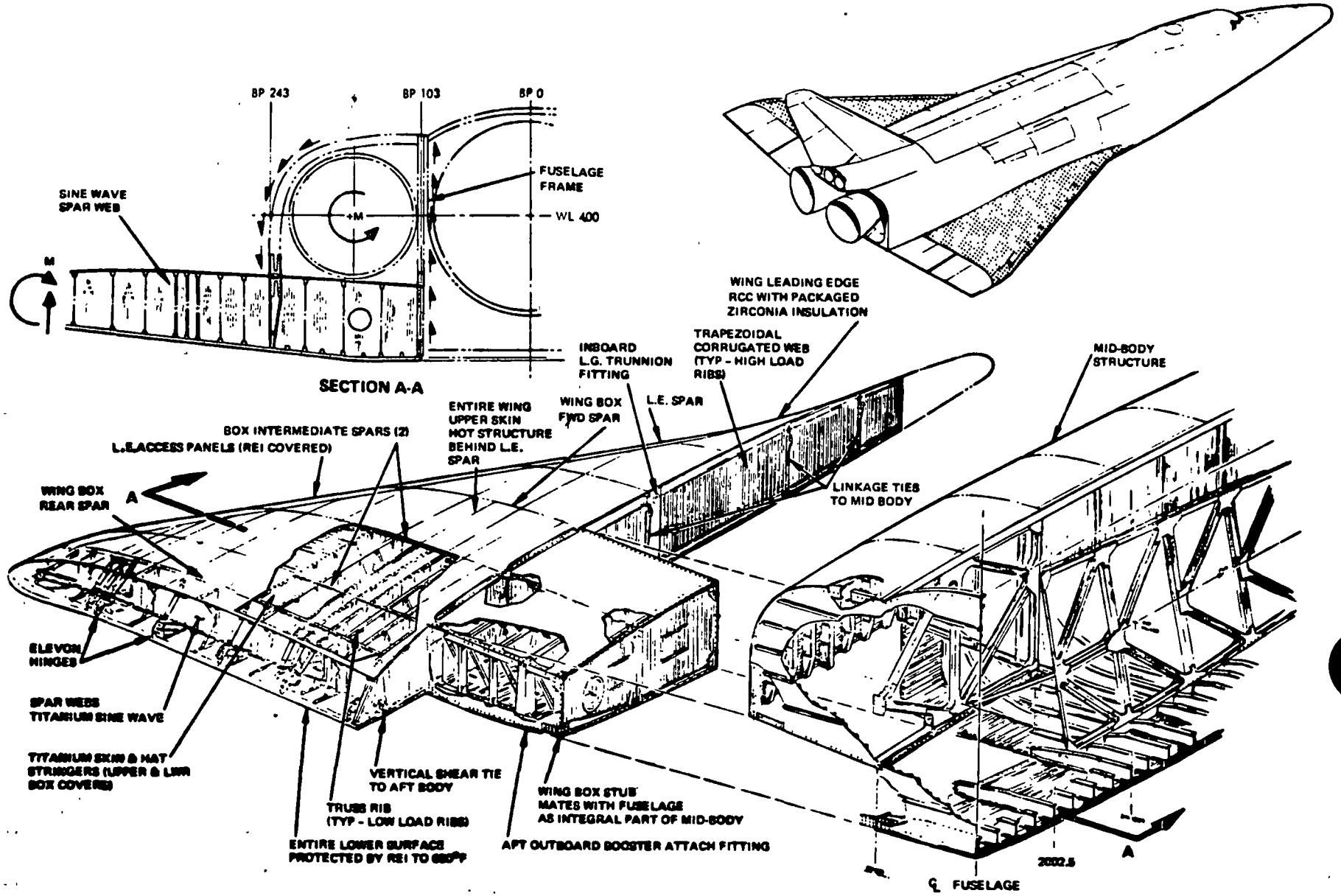


Figure 5-71. Delta-Wing Structural Arrangement

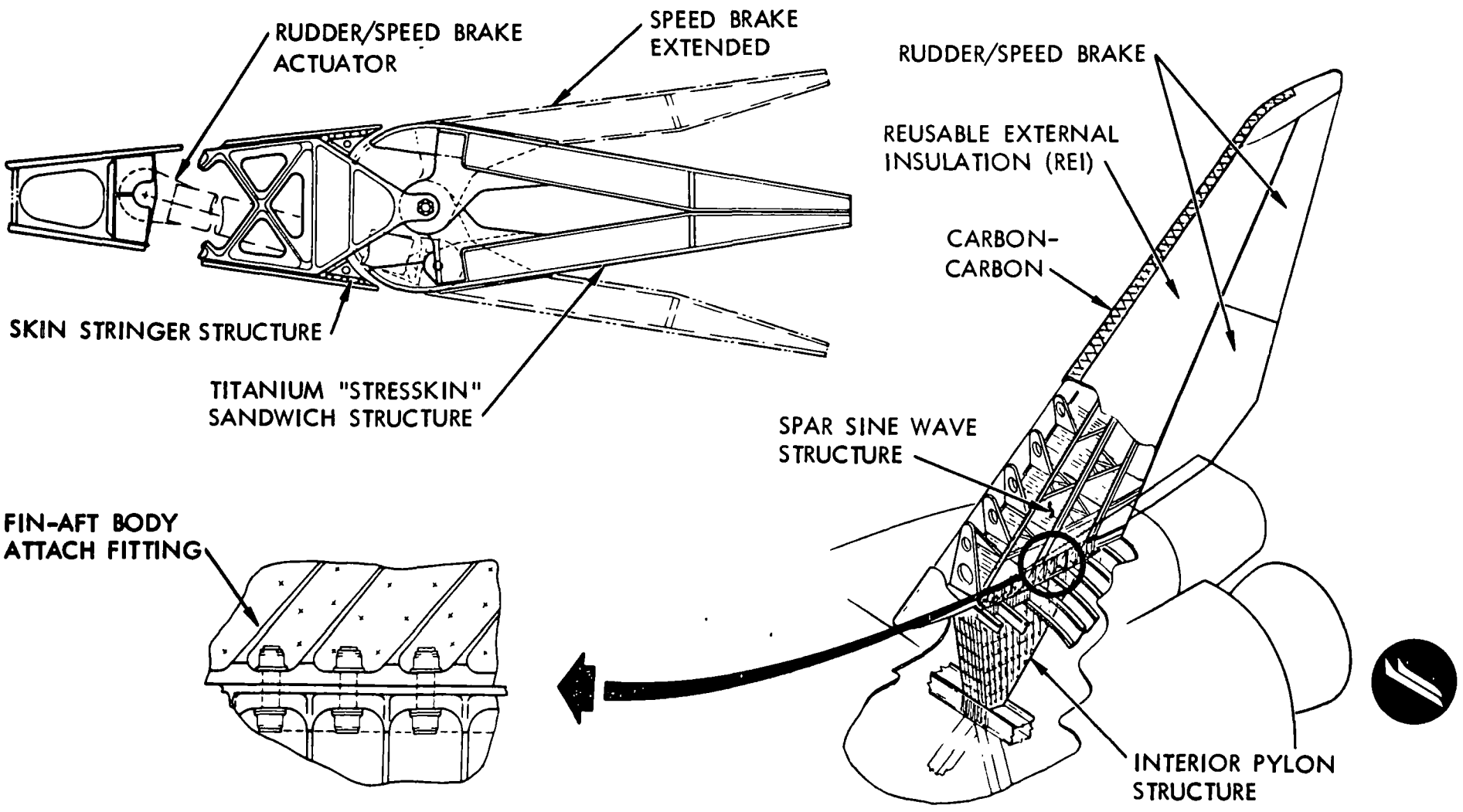


Figure 5-72. Vertical Surface Delta-Wing Orbiter

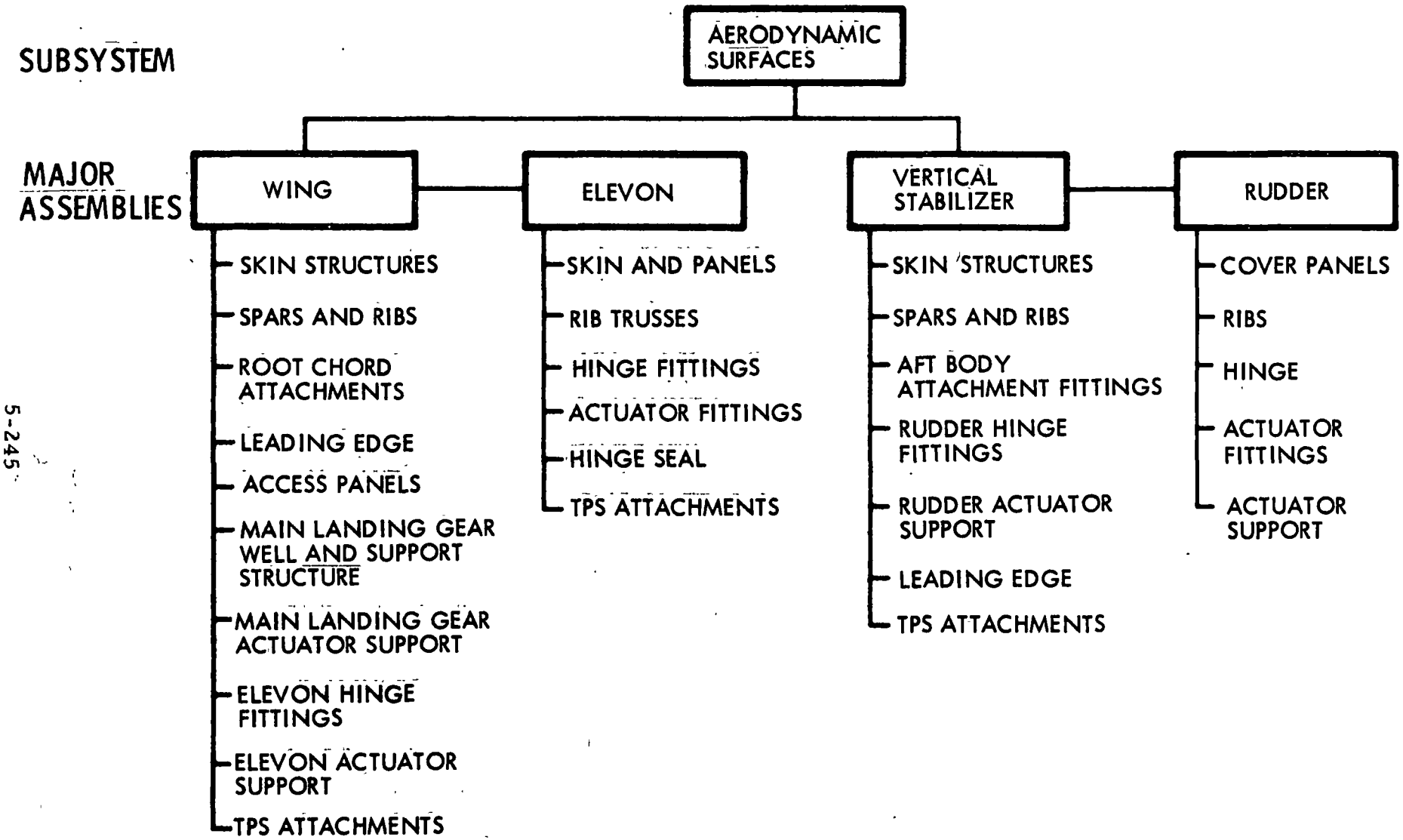


Figure 5-73. Aerodynamic Surfaces Elements

Table 5-50. Aerodynamic Surfaces Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
GENERAL TEST REQUIREMENTS							
1. Ability of the structure to sustain static design limit loads with no detrimental deformation					P		
2. Ability to sustain state design ultimate loads without rupture or collapse					P		
3. Ability to sustain fatigue loading throughout the design life times an appropriate factor of safety with no detrimental damage, or, for structures which depend on nondestructive inspection for structural life assurance, verify that these techniques are adequate to assure detection of significant defects within the safe inspection interval established in the fracture control plan.					P		
4. Fail-safe capability for those structures/mechanisms incorporating this philosophy in their design.					P		
5. Ability to withstand dynamic loading without impairing structural and functional adequacy.						P	
6. Functional adequacy of all mechanical component support structure after complete life spectrum load history					P		
7. Shear, rotational, and bending stiffnesses of aerodynamic surfaces					P		
8. Items 1 through 7 are to be verified under true or simulated environmental effects where applicable (cryo or heat)					P		
WING AND ELEVON							
1. Stiffness matrix analysis verification					P		
2. Structural integrity of the wing and carry-through structure for critical loads and thermal environment.					P		

Table 5-50. Aerodynamic Surfaces Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
3. Structural integrity of the elevon and backup structure under critical loads and thermal environment					P		
4. Structural integrity of the MLG doors and backup structure under critical loads and thermal environment				P			
5. Structural integrity of the MLG support structure under critical loads and thermal environment				P			
6. Fail-safe capability of selected areas of wing and elevon					P		
VERTICAL STABILIZER AND RUDDER/SPEED BRAKE							
1. Stiffness matrix analysis verification					P		
2. Structural integrity of vertical stabilizer and carry-through structure for critical loads and thermal environment					P		
3. Structural integrity of the combined rudder/speed brake and backup-structure for critical loads and thermal environment					P		
4. Fail-safe capability of selected areas of the vertical stabilizer and rudder/speed brake					P		
SUBSYSTEM ACCEPTANCE TESTING							
1. Function of control surfaces during rigging to actuators							P
2. Apply hydraulic pressure and servo signals to control system to extend/retract actuators and verify surface positioning							P
3. Critical clearance envelopes during (2) above							P

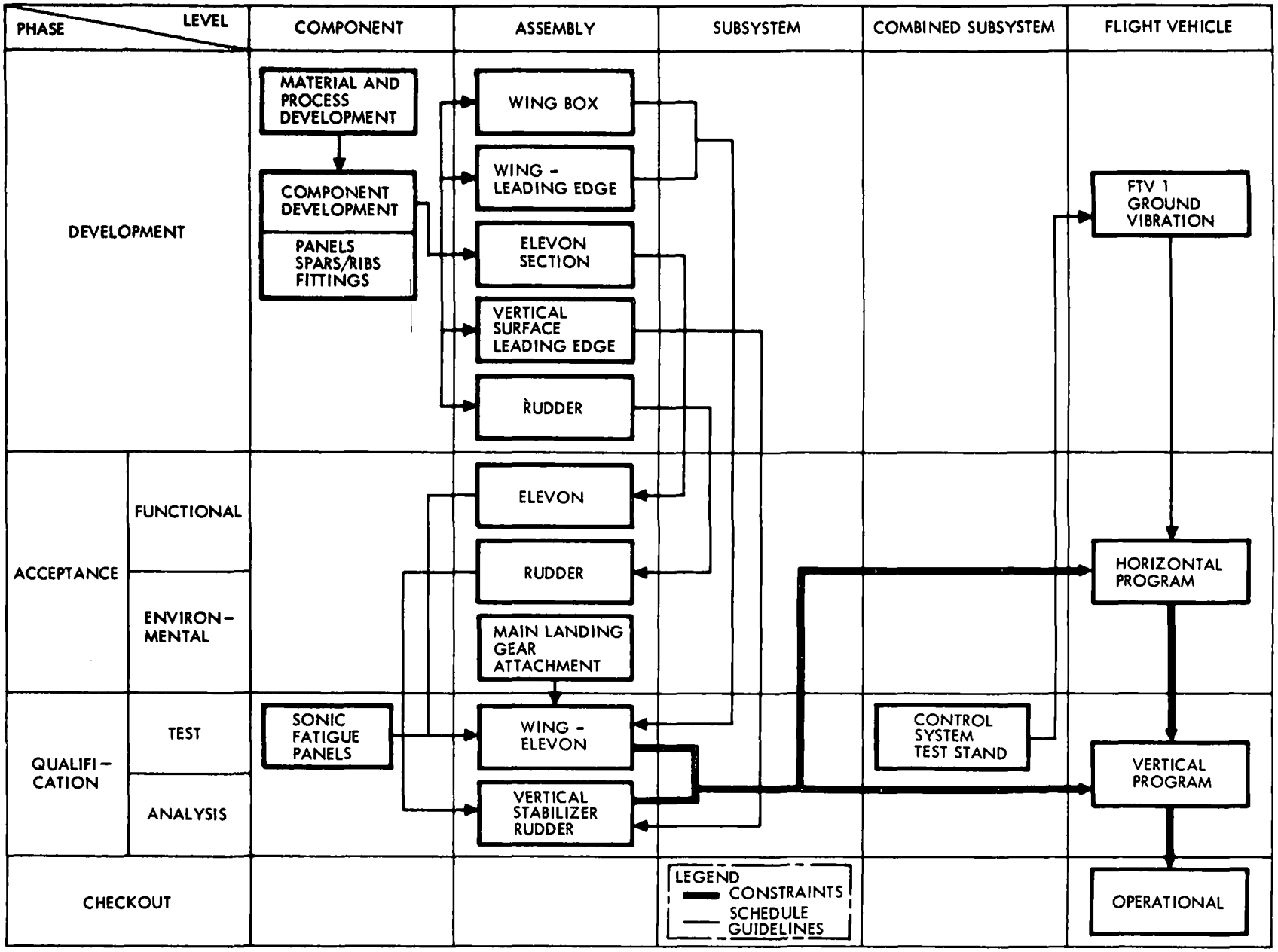


Figure 5-74. Aerodynamic Surfaces Test Logic Constraint Network

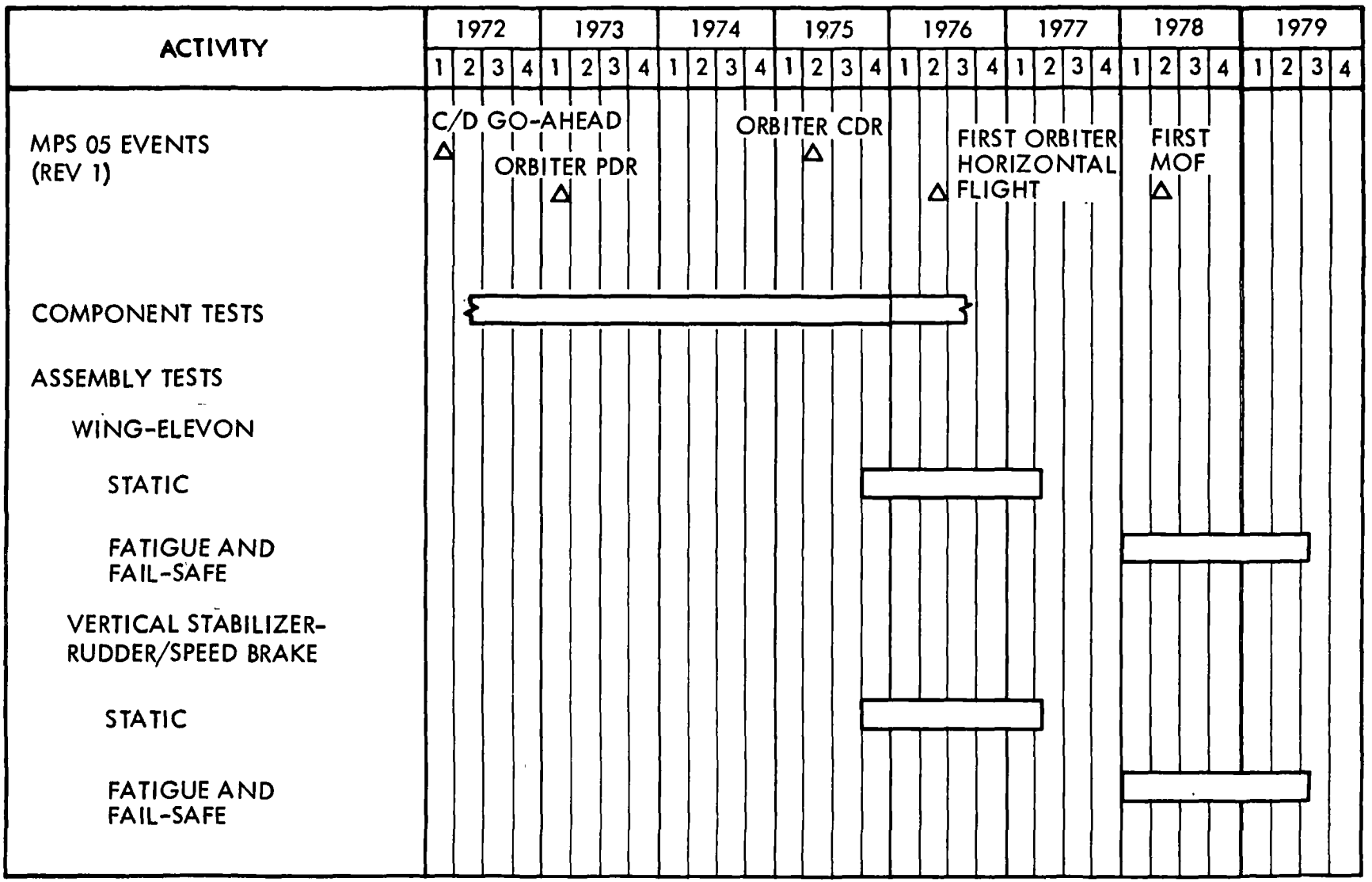


Figure 5-75. Aerodynamic Surfaces Test Schedule

Table 5-51. Aerodynamic Surfaces Test Article Requirements

Assembly	Type of Test	Quantity
*Wing: left half right half	Qualification, static and fatigue	1 1
*Elevon	Qualification, static and fatigue	2 (1 LH, 1 RH)
*Vertical stabilizer	Qualification, static and fatigue	2
*Rudder/speed brake	Qualification, static and fatigue	2
Typical TPS panels	Qualification, static and fatigue	3%

Note: The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.

*These are the same items used with Test Article C of Table 5-48.

Table 5-52. Aerodynamic Surfaces Structural Test Support Requirements

Item	Requirement			
Facilities	1. Covered structural test area*	Length (ft)	Width (ft)	Height (ft)
	a. Wing (on body structure)	210	110	75
	b. Elevon	50	40	30
	c. Vertical stabilizer (on body structure)	210	110	75
	d. Rudder/speed brake	50	30	30
	2. Hydraulic power	gpm at 5000 psi		
	a. Wing (on body structure)	100		
	b. Elevon	40		
	c. Vertical stabilizer	40		
	d. Rudder/speed brake	20		
	3. Electrical power	kva at 440 to 600 vac (3Ø)		
	a. Wing	6000		
	b. Elevon	2000		
	c. Vertical stabilizer	2000		
	d. Rudder/speed brake	1000		
	*Assumes static and fatigue tests utilize same test fixtures.			

Table 5-52. Aerodynamic Surfaces Structural Test Support Requirements (Cont)

Item	Requirement		
Support Equipment	1. Load programming	Program Channels	Servo Channels
	a. Wing	4	40
	b. Elevon	2	10
	c. Vertical stabilizer	2	10
	d. Rudder/speed brake	2	10
	2. Heat Programmers		
	a. Wing	6	72
	b. Elevon	2	12
	c. Vertical stabilizer	6	18
	d. Rudder/speed brake	2	12
	3. Data acquisition	Channels	
	a. Wing	1000	
	b. Elevon	150	
	c. Vertical stabilizer	300	
	d. Rudder/speed brake	100	
Software	Programming as required for heat and load control and data acquisition and processing.		

5.16 THERMAL PROTECTION SUBSYSTEM

5.16.1 Description

The space shuttle thermal protection subsystem (TPS) is designed to protect the primary load-carrying airframe structure from destructive elevated temperatures imposed during entry into the earth's atmosphere. The TPS is provided by reinforced pyrolized plastic (RPP) and/or reusable external insulation (REI). RPP is typically used in the wing and empennage leading edges, fuselage nose section, nose wheel door, and other areas exposed to temperatures in the 2500 F region. REI is used in other areas of the shuttle vehicle (fuselage, wing, and tail surfaces) where the surface temperatures exceed allowable ranges for the basic titanium structure. Figures 5-76 shows typical RPP and REI installations on a wing leading edge section.

Figure 5-77 depicts the three design concepts of REI installation on the orbiter vehicle. The first design configuration, common to both Block I and Block II vehicles, represents the REI panel installation in the integral tank area. The second configuration shows a Block I design of typical REI panel attachments to the primary wing or fuselage structure. Both of these configurations have no in-plane load carrying capability. The third configuration represents a Block II design for REI insulation installed directly on the primary structure of the wing or fuselage. With this design the REI insulation will be subjected to all loads and environments imposed on the shuttle air frame structure.

The TPS also includes special panel design configurations to accommodate component penetrations, such as the ACPS nozzles, vents and antennas, as well as special provisions for the elevon and rudder hinge fittings and similar local design problem areas.

5.16.2 Requirements

The thermal and structural integrity of each configuration of the TPS will be verified by analysis and tests for the TPS critical design load and temperature profiles. The TPS subsystem certification requirements are summarized in Table 5-53.

5.16.3 Approach and Rationale

Adequate development and certification of a cost-effective, weight-optimized, thermal protective system will require a two-phased approach. Design confidence for initial flights will be provided by the Block I TPS design, which will have specific design allowances for uncertainties that require full-scale flight testing for resolution or verification. The Block I TPS will be certified for the initial orbital launch/entry flights through extensive ground testing at the component and assembly level. The first orbital flight profiles will be restricted to maintain thermal structural adequacy to well within demonstrated limits. Additionally, a 100-mission, or a two-week turnaround capability will not be a TPS requirement for the initial flights.

As flight test data are obtained from the initial orbital flights, the data will be utilized to certify each subsequent flight until sufficient data are accumulated for analytical certification for all design entry profiles.

Certification of the Block II TPS will be accomplished in a similar but less extensive manner.

The TPS test program will encompass material and process testing, structural development testing, and acceptance and qualification testing, as shown in Figure 5-77.

Material and process testing will be performed to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the TPS subsystem. Areas to be investigated include the following:

1. The ability of seals, sealants, lubricants, and grease to function under mission requirements for temperature, pressure, loads and exposure time.

2. The flamability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Performance of thermal control coatings under long duration earth-orbital exposure and launch entry thermal profiles.

4. Compatibility of materials in contact with each other in environments that could result in degradation of properties.

5. Compatibility, stability, and thermal and physical characteristics of fiberous (bulk) insulation.

6. Effects on structure system of corrosion with regard to useful life candidate materials.

7. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

8. Physical and mechanical properties of shuttle materials which have not been established previously.

9. Joining methods for candidate alloys for shuttle structural and thermal requirements.

10. Determination of design allowables and oxidation resistance of reinforced pyrolyzed plastic (RPP) materials.

11. Development, design, fabrication, and verification of reusable external insulation (REI) for the orbiter thermal protection system.

12. Development of materials accelerated life-test methods.

TPS development testing will be performed early in the program to provide test data on critical or difficult to analyze areas. This will provide knowledge of internal load and temperature distribution in areas of configuration complexity. Typical REI development tests to be conducted are as follows:

1. Thermostructural performance. Bi-material composite beams and panels will be subjected to various heating, cooling, loading, thermal cycling, and dynamic conditions: to ascertain that the proposed heat shield can survive the shuttle flight environments; to determine types of failures; and to correlate analytical predictions with experimental results.

2. Evaluation of cold soak. Bi-material sandwich panel specimens are to be subjected to simulated deep space environment (programmed cold soak to -170 F). The test objective is to evaluate the bi-material thermal-structural performance and stress characteristics of the REI and the substructure under shuttle mission conditions.

3. Flat panel reentry. Bi-material sandwich panel specimens are to be subjected to a programmed heating of the critical shuttle reentry trajectory. The test objective is to evaluate the

bi-material thermal-structural performance of the REI, edge members, seals and carrier panel joints, and to ensure that the back face temperature does not exceed the design requirement.

4. Temperature gradient. REI panel specimens are to be subjected to a programmed mission profile thermal gradient through the thickness of the REI. The test objective is to evaluate the integrity of the system when subjected to critical design temperature gradients.

5. Beam test. Bi-material sandwich beams are to be subjected to bending tests under a theoretical programmed cold soak and also a thermal programmed critical reentry heat condition. The test objective is to evaluate and establish the structural strain compatibility between the REI and the titanium substructure under environmental loading conditions. The beam tests will also be used to determine the loading that will cause catastrophic failure (delamination of the REI from the substructure). Before the above tests, specimens will be used to evaluate the bi-material zero stress state of the fabricated composite structure.

6. Special design problem areas. Typical bi-material specimen, illustrating such fittings as umbilicals, window joints, antennas, and/or other areas causing stress concentrations and perturbations to the REI panels, will be tested to in-plane loads and shuttle environments. The basic objective of these tests will be to ensure that the special design areas will satisfactorily perform their design functions.

Similar thermo-structural development tests will be conducted on curved panels and typical leading edge configurations for the RPP type of insulation.

Acceptance testing, designed to demonstrate the flight worthiness of each delivered TPS panel, will primarily consist of careful visual inspection and application of nondestructive test (NDT) techniques to evaluate the integrity of the RPP and REI panels relative to delamination, bonding voids, porosity, and cracks.

Qualification tests of the RPP and REI TPS concepts will be conducted on both component and assembly levels as part of the overall subsystem certification, culminating with final evaluation of flight test data. During the ground test program, component panels will be installed on local areas of high strain on the static test vehicle to obtain induced strain measurements. In addition, selected TPS panels in high noise level environments will be

tested for sonic fatigue and buffet effects, as described in Structural Dynamics, Section 6.8. Figure 5-78 presents the test logic and constraint network and Figure 5-79 shows the proposed test schedule.

5.16.4 Test Article Requirements

Test article requirements are given in Table 5-54.

5.16.5 Support Requirements

Table 5-55 presents facility and equipment support requirements.

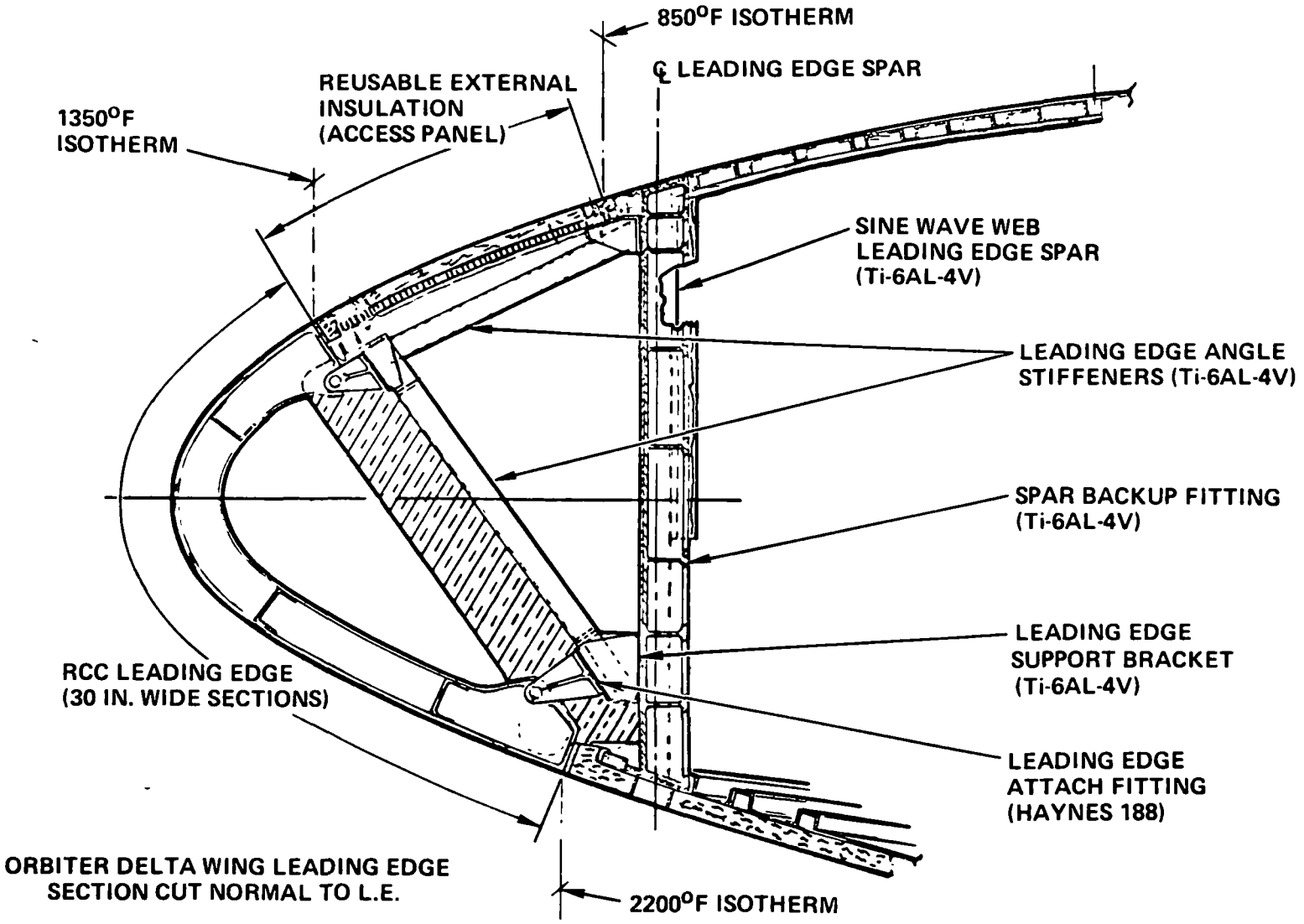


Figure 5-76. Wing Leading Edge

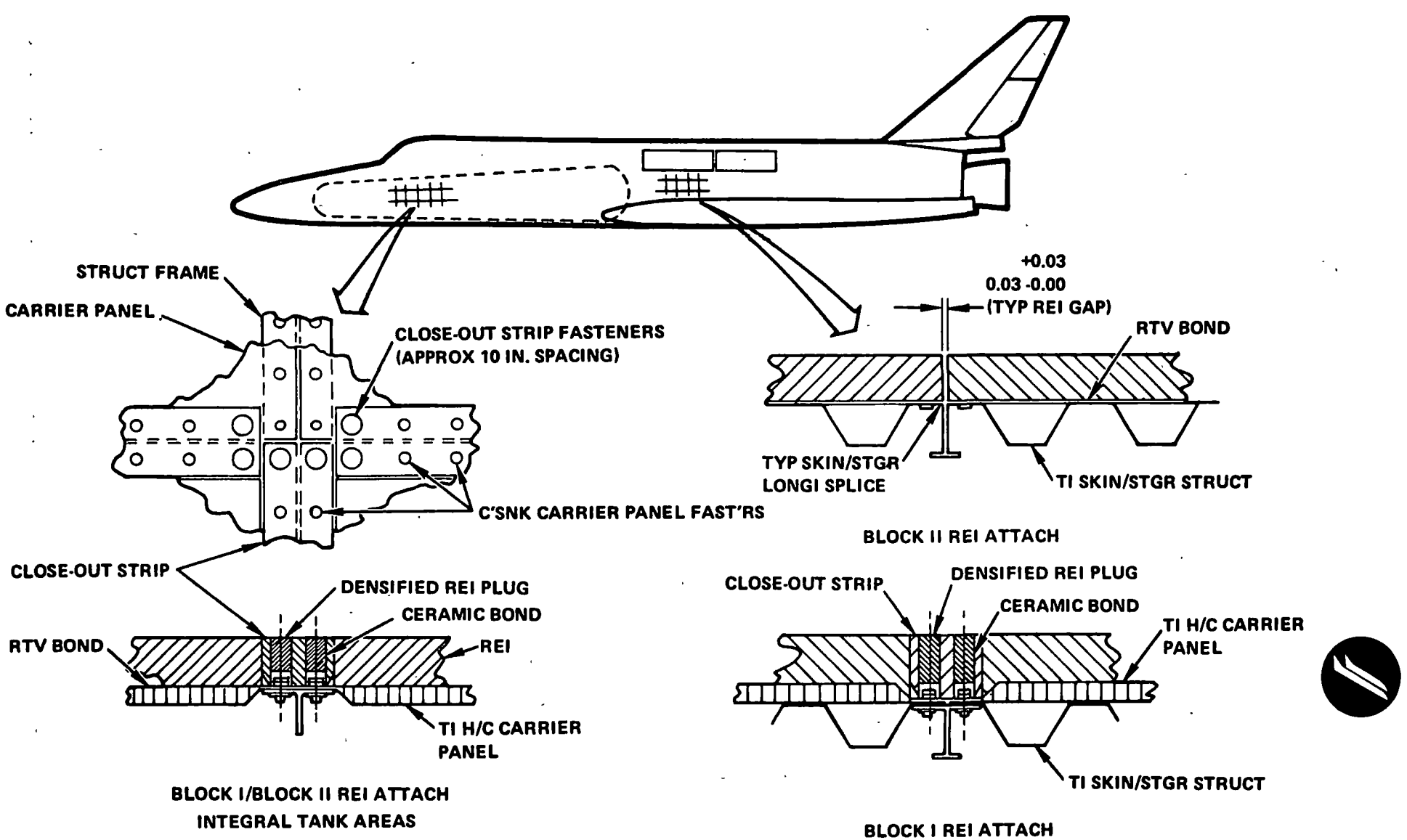


Figure 5-77. REI Block I/Block II Attach

Table 5-53. Thermal Protection Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
1. Ability to sustain static limit loads without detrimental deformation			P	S			
2. Ability of REI to sustain static limit loads times an appropriate factor of safety without cracking			P	S			
3. Ability to sustain static ultimate loads without rupture or collapse			P	S			
4. Ability of REI to sustain static ultimate loads without delamination			P	S			
5. Ability to sustain repeated loads and environments for the design life of the vehicle with an applied factor of safety			P	S			S
6. Ability to withstand dynamic loading without impairing structural and functional adequacy			P	S			S
7. Items 1 through 6 above with environmental effects, where applicable			P	S			S
8. Verify TPS component installation (penetrations, seals, etc.) for critical loads and thermal environments			P				S
9. Capability of TPS and TPS components for multi-reuse for operational usage							P

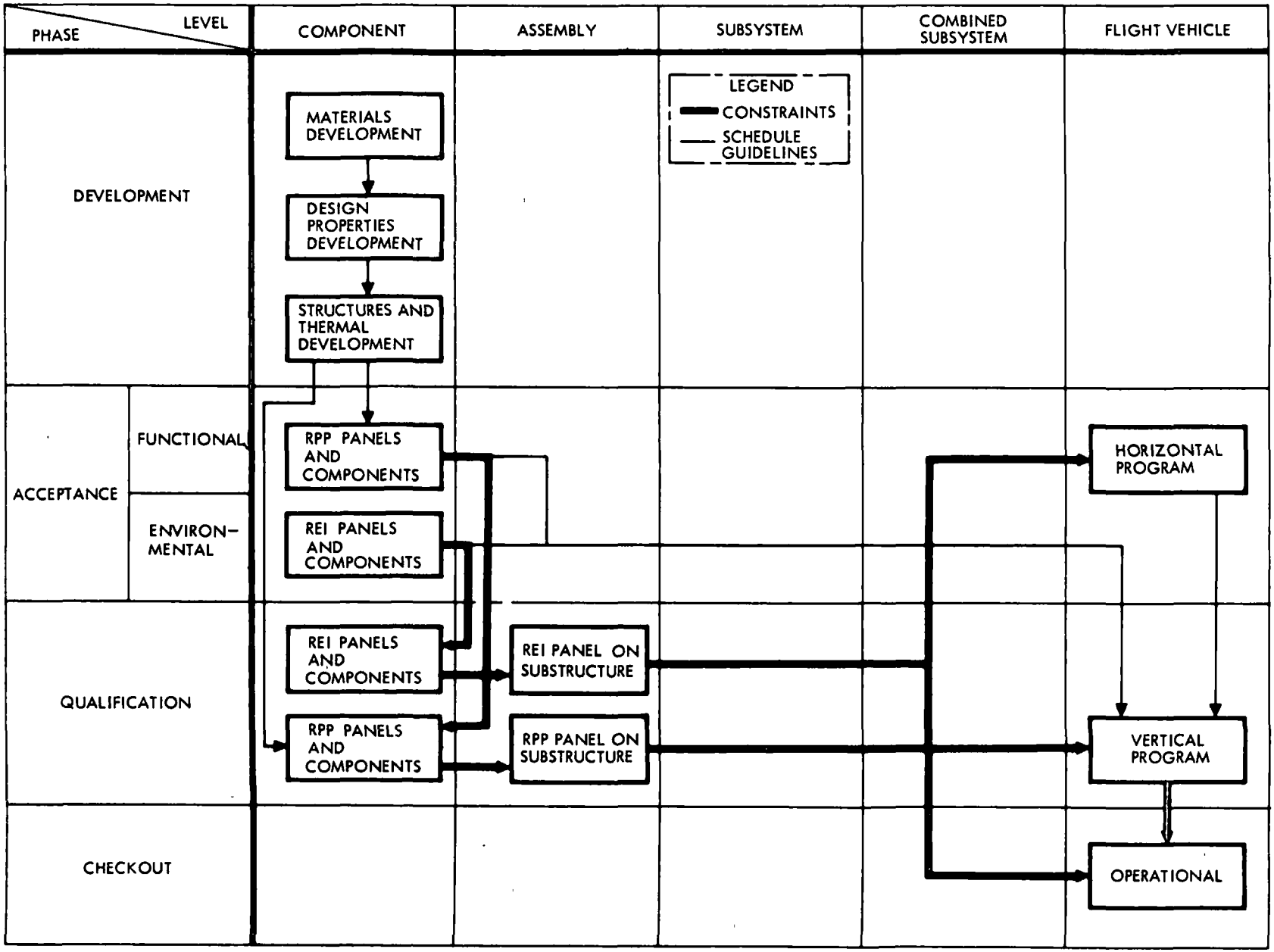


Figure 5-78. Constraint Test Network

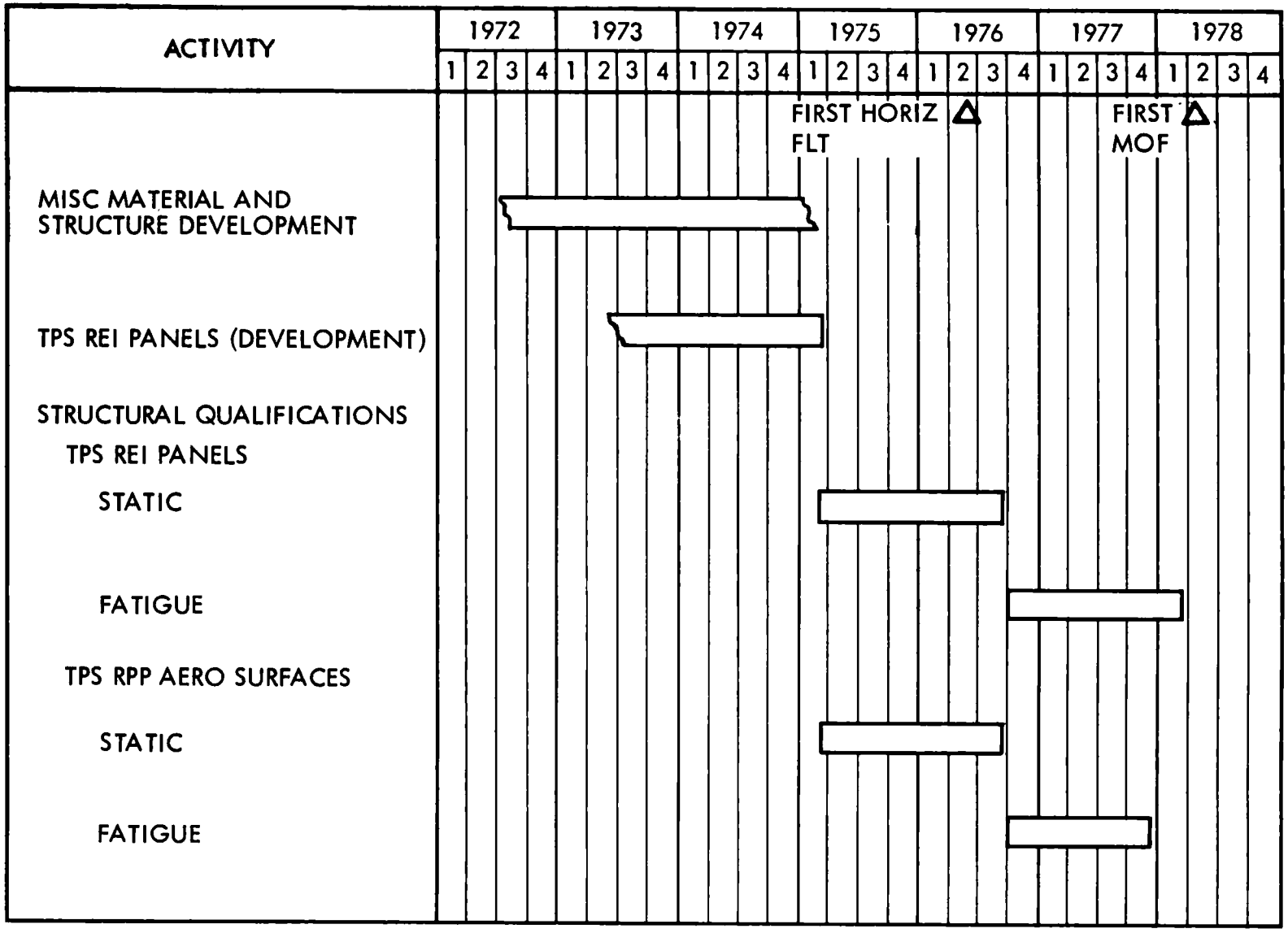


Figure 5-79. Thermal Protection System Phase C/D Schedule

Table 5-54. TPS Test Article Requirements

Description	Quantity
Typical curved and flat TPS panels of RPP and REI construction	3%
Note: The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.	

Table 5-55. TPS Test Support Requirements

Item	Requirements
Facility	Electrical power 60 cycles, three-phase 440v, 2000 kva Mechanical properties laboratory Thermal properties laboratory Plasma arc facility
Support Equipment	Radiant heat programmers and controls Load programmers and controls Servo actuators Environmental simulation chambers Strain and deflection transducers Data recording and processing equipment
Software	Programs to implement load and thermal profile simulations Programs to reduce recorded data and correct for environmental effects

5.17 LANDING SUBSYSTEM

5.17.1 Description

The landing subsystem consists of three major assemblies: a nose landing gear, a main landing gear (left and right) and a deceleration parachute. Figure 5-80 shows the integrated landing subsystem hierarchy, the landing subsystem is shown in Figure 5-81.

The nose gear assembly is made up of a shock strut, dual wheels and tires, drag brace, trunnion fittings, gear actuation and indication systems, uplock, downlock, steer/shimmy damper, fairing door, door actuation and locking mechanism (Figure 5-82).

Each main gear is made up of a shock strut, dual wheels, brakes and tires, drag brace, trunnion fittings, gear actuation and indication systems, uplock, downlock, anti-skid brake control, fairing door, door actuation and locking mechanism (Figure 5-83).

The deceleration parachute assembly is made up of one main drag chute, one drogue (pilot) chute and deployment mortar, structural attach fittings, jettison mechanism, and actuators (Figure 5-84).

The landing gear, brakes, and steering are hydraulically powered and electrically controlled. The gears retract forward resulting in "free fall" emergency gear extension capability.

The deceleration parachute is disconnected from the vehicle during flight by means of the jettison hook being in the "open" position. This is to safeguard the structure in case of inadvertent deployment of the chute during flight. The deceleration chute is designed for use only after landing touchdown. Deployment is initiated by the pilot positioning a two-position switch to the "deploy" position, resulting in the following sequence of events:

1. Jettison hook closes, thereby securing drag chute riser to vehicle structure.

2. Mortar launches drogue chute.

3. Drogue chute inflates and pulls main canopy from container.

Following deployment, the pilot may jettison the drag chute by returning the selector switch to the original "STOW/Jettison" position which causes the jettison hook to open and release the chute.

5.17.2 Requirements

The landing subsystem test requirements are outlined in Table 5-56, and have been categorized by method of verification.

5.17.3 Approach and Rationale

Approach and rationale to be used in the development, acceptance, and qualification test program for the landing subsystem is presented in the landing subsystem test logic and constraint network (Figure 5-85).

To support component development and related subsequent requirements of the landing subsystem, material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials and the processing of materials for use in the landing subsystem. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seals, lubricant, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Compatibility of materials in contact with each other in environments which may result in degradation of properties.

4. Effects of structural and fluid system corrosion on useful life of critical materials.

5. Optimization of special welding techniques verified by mechanical and nondestructive tests.

6. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

7. Physical and mechanical properties of shuttle materials which have not been previously established.

8. Joining methods for candidate alloys for shuttle structural and thermal requirements.

9. Development of materials accelerated life-test methods.

10. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat treat cycles, and metallurgical joints.

Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, and assembly level. Subsystem and combined subsystem level ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6.

It is anticipated that a portion of the mechanical components and major subassemblies of the landing gear will be designed, developed, and (to some extent) qualified by a subcontractor. Qualification tests shall be conducted by the suppliers for the shock struts, wheels, tires, and brakes, because these items must be tested on special equipment (drop test towers and/or very large dynamometers). The brake control system and antiskid system will be included in the dynamometer brake testing program to assure compatibility of the integrated systems.

It is not considered necessary to conduct the full spectrum of environmental testing of landing gear equipment. Qualification by similarity to existing hardware should provide cost savings to the program with little or no risk to mission success. However, all equipment items will be assessed as to the need for any particular element of the environmental tests (e.g., vacuum testing of nonmetallic components and vibration testing of the uplock mechanisms).

One nose and one main landing gear will be used first for metering pin development drop tests, and second for system functional tests on the landing gear simulator.

Fatigue tests will be conducted on an additional set of one nose and one main landing gear, each complete with braces, actuators, locks, etc. No wheels, tires, or brakes are required. Both gears will be installed in test jigs simulating support structure and initially static tested to their critical limit design loads prior to the first horizontal flight. Assuming 100 horizontal flights plus 100 missions per life, the fatigue load spectrum will then be applied on a ground-air-ground basis for 200 flights times a scatter factor of four, or 800 flights.

Final qualification testing of the drag chute, steering, and brake systems will be accomplished during taxi tests on the first orbiter flight test vehicle.

Landing gear operational and endurance tests will be conducted on the landing gear simulator (working mockup). The nose gear and one main gear

will be complete with doors, drag braces, gear and door locks, actuators, hydraulic system (including valves, flow regulators, etc.), electrical control and indicator systems. Tests on the simulator will include:

1. Retraction/extension kinematics and clearance checks.

2. Integrated systems checks (hydraulic, electrical, and mechanical operating rates, sequencing, dynamic accelerations, and electrical indicating switches).

3. Simulated air loads (on gears and doors) to test operational power, retraction/extension time, etc.; also, to proof test doors and locks under simulated high speed air loads (gear-up in flight).

4. Endurance tests to demonstrate satisfactory wear life, fatigue life and integrated systems reliability (800 normal and 200 emergency retraction/extension cycles).

The landing gear simulator provides a means for early check out of all operational systems, while time is available to correct possible deficiencies before manufacturing is complete on flight hardware. This is a well-proven method of ensuring against impacting flight test and delivery schedules.

Figure 5-85 presents the test logic and constraints network. A preliminary test schedule is shown in Figure 5-86.

Additional static ultimate land and fatigue tests will be conducted on the main and nose gear doors and door backup structure as part of the body structural test program described in Section 5.14.

5.17.4 Test Article Requirements

Test hardware requirements are summarized in Table 5-57.

5.17.5 Support Requirements

Developmental testing of landing subsystems design concepts (breadboard and working mockups tests) will be conducted in an engineering experimental shop area. Most of the qualification testing, other than supplied equipment, will be conducted in environmental and structural test laboratories.

Portable GPU equipment will be required to supply hydraulic and electrical power for operational checkout tests of the landing gear and drag chute mechanism. A low-rate air bottle and cable system must be assembled for use in simulated air loads tests.

Computer software required to support landing subsystem testing includes landing loads analysis and vehicle dynamics during landing and deceleration (aerodynamic drag, wheel brakes and drag chute).

Support requirements are summarized in Table 5-58.

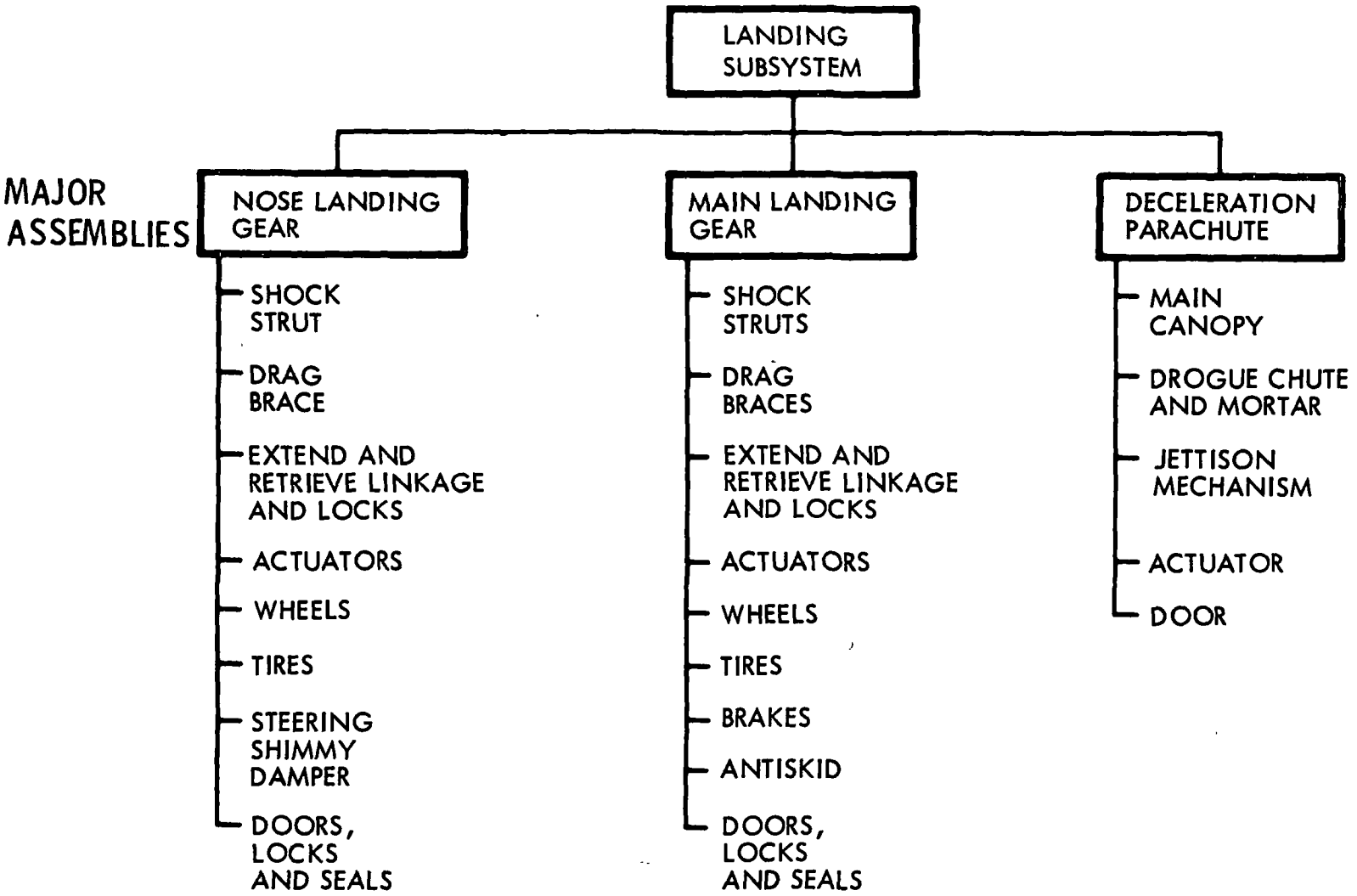


Figure 5-80. Landing System Elements

- TRICYCLE GEAR
- DUAL WHEELS
- FREE FALL
- HEATED WHEEL WELLS
- DRAG CHUTE SYSTEM (TYPE I)

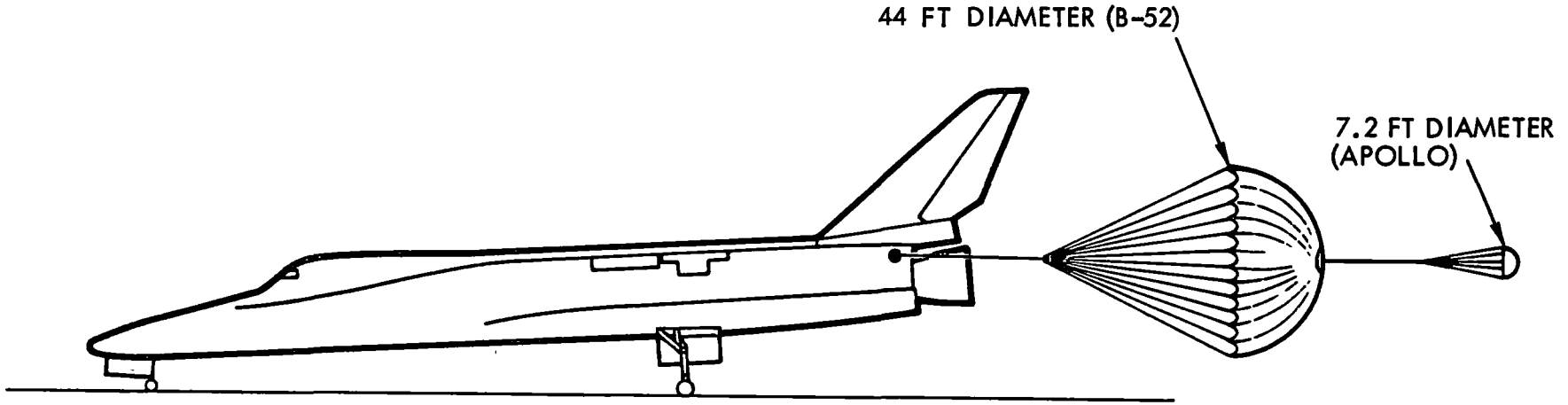


Figure 5-81. Landing System

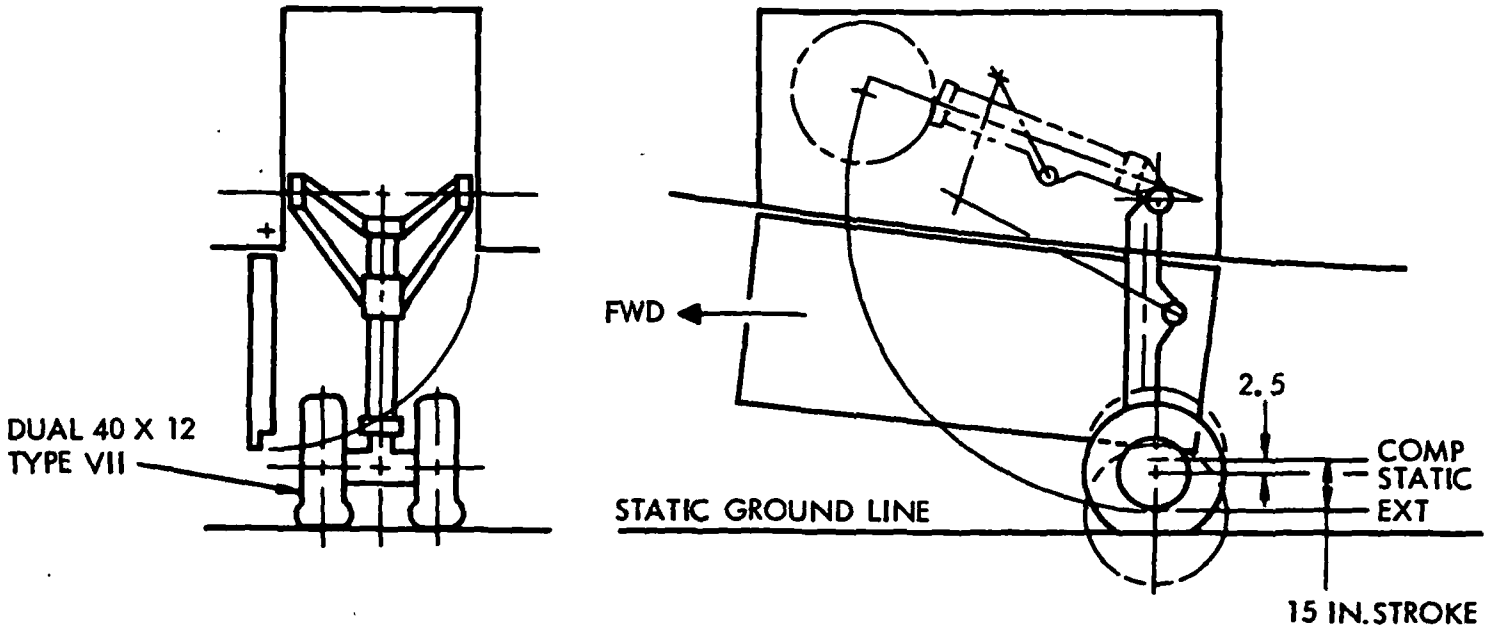


Figure 5- 82. Nose Gear Installation

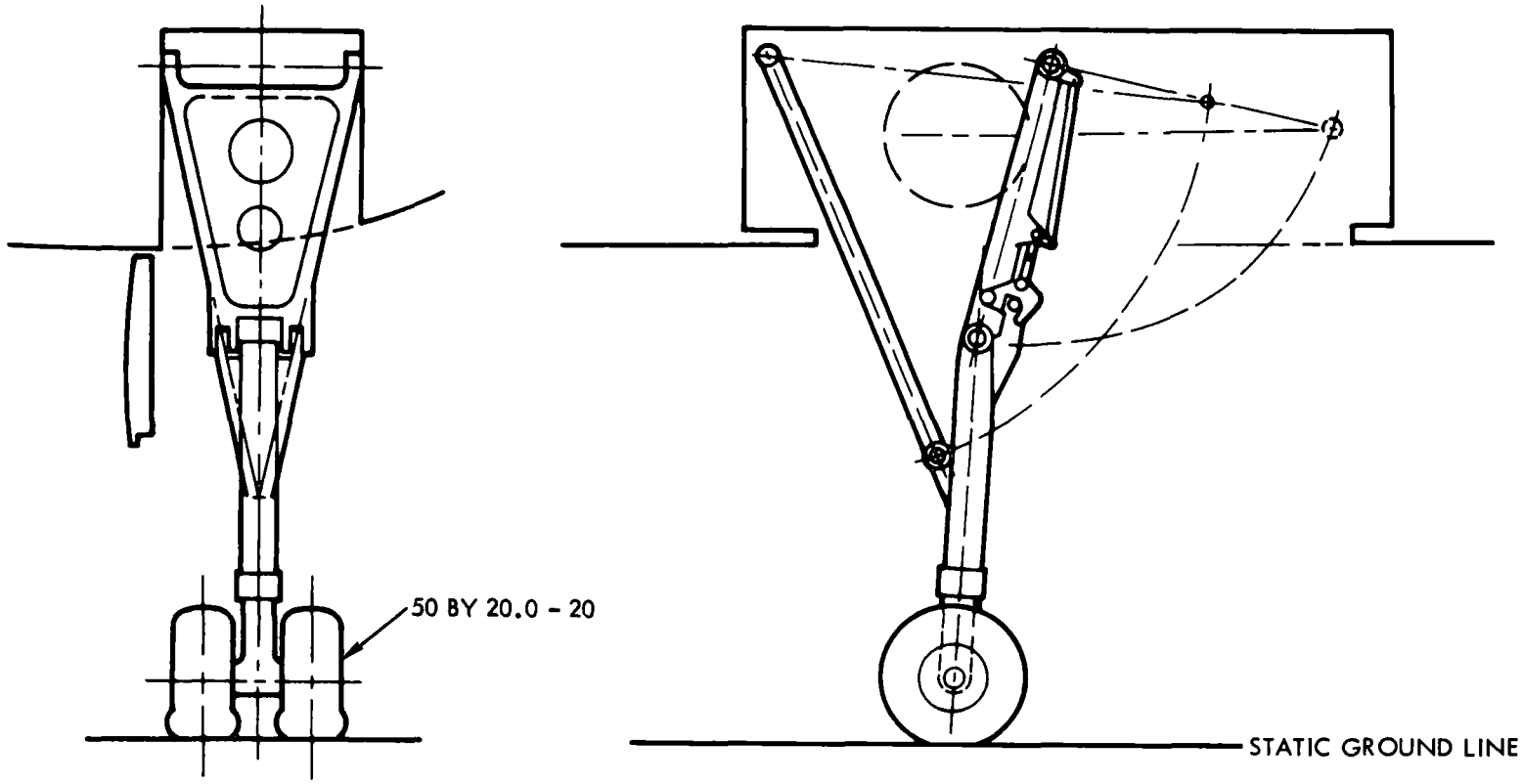


Figure 5-83. Main Gear Installation

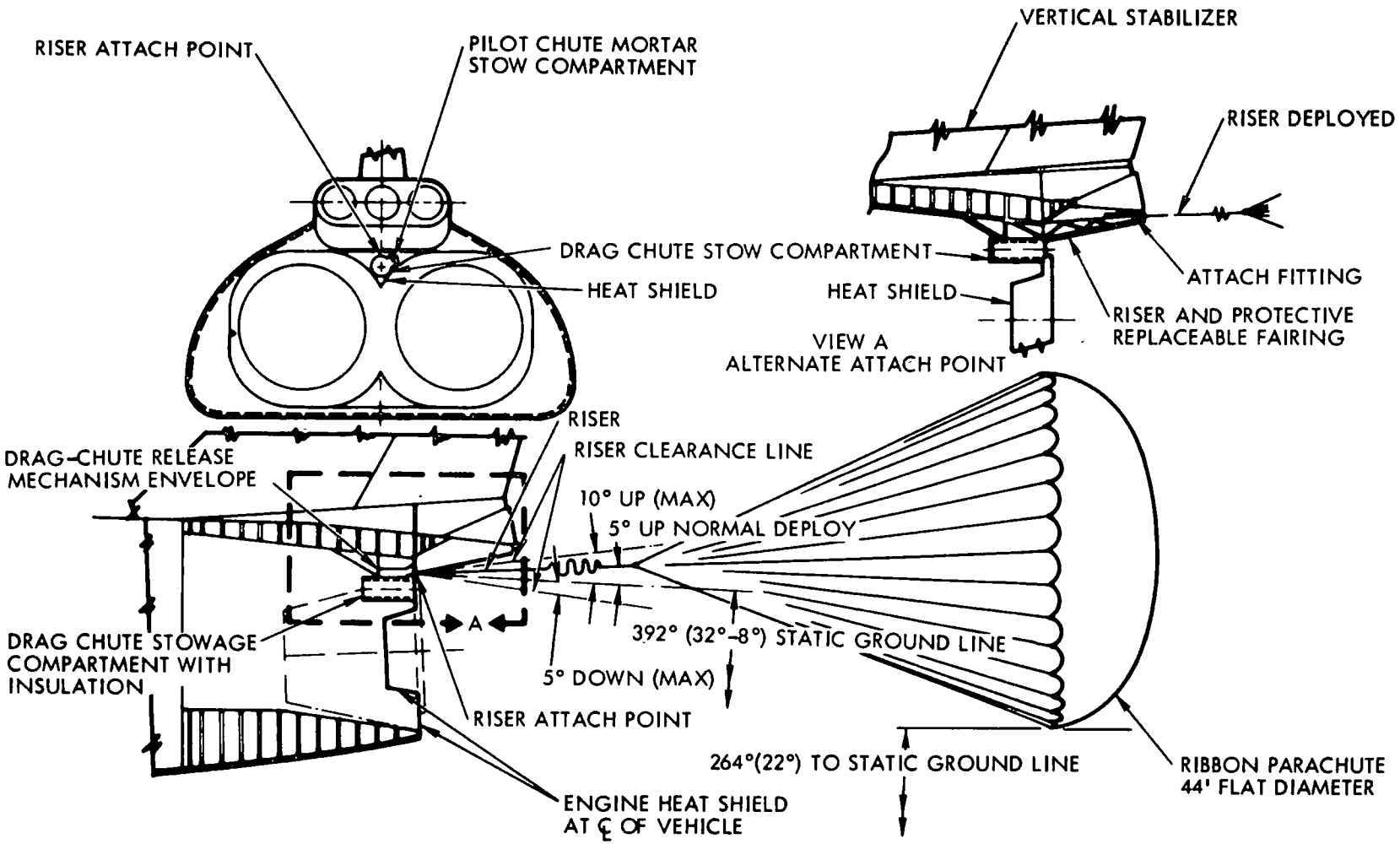


Figure 5-84. Deceleration Parachute Subsystem

Table 5-56. Landing Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
NOSE GEAR SUBSYSTEM							
1. Nose wheel steering and shimmy damping characteristics.					S		P
2. Functional operation of nose landing gear, including electrical and hydraulic equipment, doors, uplocks and downlocks, for extension and retraction under aerodynamic and inertia loads. Demonstrate adequate wear life, fatigue life and integrated systems reliability. Demonstrate normal, alternate and emergency modes of gear extension.				P			
3. Shock strut damping characteristics.				P			
4. Structural integrity of the gear for repeated landing loads.				S	P		
5. Structural and functional adequacy of the wheel assembly under static and fatigue loading, generally in accordance with MIL-W-5013G.				S	P		
6. Structural and functional adequacy of the tire, generally in accordance with MIL-T-5041E, including applicable thermal and vacuum environment.			S	P			
7. Functional adequacy of steering system after exposure to space environment, generally in accordance with MIL-S-8812C.			P				
8. Structural/functional adequacy of doors, hinges, locks and seals.			S				P
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Verification of uplock, downlock, and NLG actuator, door mechanism, and brake system adjustments.							P
2. Verification of shock strut and tire servicing procedures.							P

Table 5-56. Landing Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
IN-PROCESS CHECKOUT REQUIREMENTS (Cont)							
3. Verification of proper NLG actuation, sequencing and cockpit controls and displays.							P
4. External leakage through mechanical, brazed, or welded tube joints does not exceed specifications.							P
MAIN GEAR SUBSYSTEM							
1. Functional adequacy of brakes and antiskid control system.					S		P
2. Functional operation of main landing gear, including electrical and hydraulic equipment, doors, uplocks and downlocks, for extension and retraction under aerodynamic and inertia loads. Demonstrate adequate wear life, fatigue life, and integrated systems reliability. Demonstrate normal, alternate, and emergency modes of gear extension.					P		
3. Shock strut damping characteristics					P		
4. Structural integrity of the gear for repeated landing loads.				S	P		
5. Structural and functional adequacy of the wheel assembly under static and fatigue loading, generally in accordance with MIL-W-5013G.				S	P		
6. Structural and functional adequacy of the tire, generally in accordance with MIL-T-5041E, including applicable thermal and vacuum environment.			S	P			
7. Structural/functional adequacy of brakes, control system, and antiskid system after exposure to space environment, generally in accordance with MIL-W-5013G, MIL-B-8584B, and MIL-B-8075C.				S	P		
8. Structural/functional adequacy of doors, hinges, locks, and seals.			S				P

Table 5-56. Landing Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Verification of uplock, downlock, MLG actuator, door mechanism, and brake system adjustments.							P
2. Verification of shock strut and tire servicing procedures.							P
3. Verification of proper MLG actuation, sequencing, and cockpit controls and displays.							P
4. External leakage through mechanical, brazed, or welded tube joints does not exceed specifications.							P

Table 5-56. Landing Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
DECELERATION PARACHUTE SUBSYSTEM							
1. Functional performance of drag chute system.			S				P
2. Functional adequacy of the system for deployment and jettisoning of the drag chute after exposure to space environment, generally in accordance with MIL-D-9056A.				S	P		
3. Functional adequacy of drogue mortar subsystem.				S	P		
4. Structural integrity of riser attach fittings, jettison mechanism and structure.				S			P
IN-PROCESS CHECKOUT REQUIREMENTS							
1. Verification of adjustment of actuator, door, and jettison mechanism.							P
2. Verification of operation of actuator, door, jettison mechanism, cockpit controls, and displays.							P
3. Verification of mortar firing circuit continuity and voltage.							P

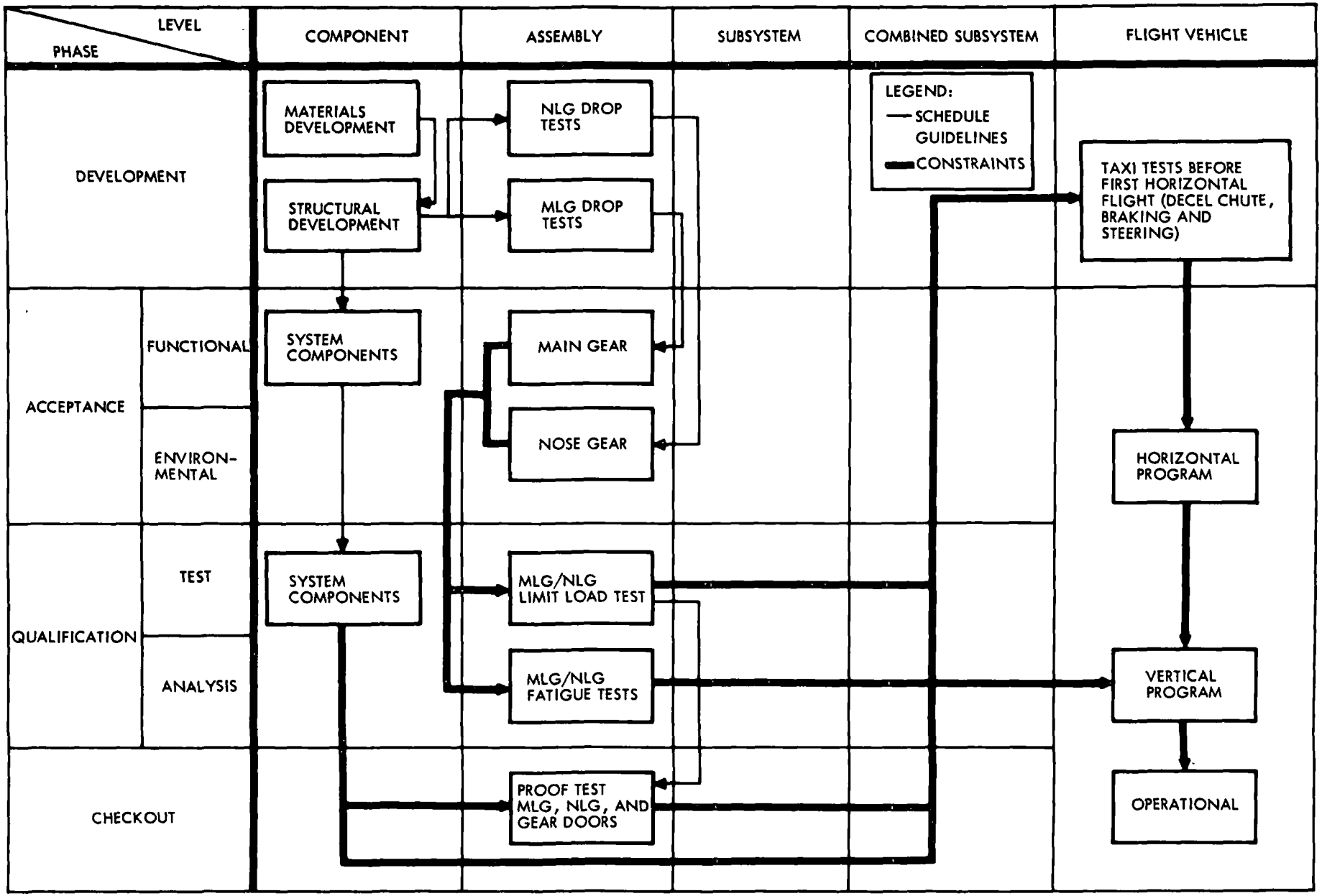


Figure 5-85. Landing Subsystem Test Pages and Constraint Networks

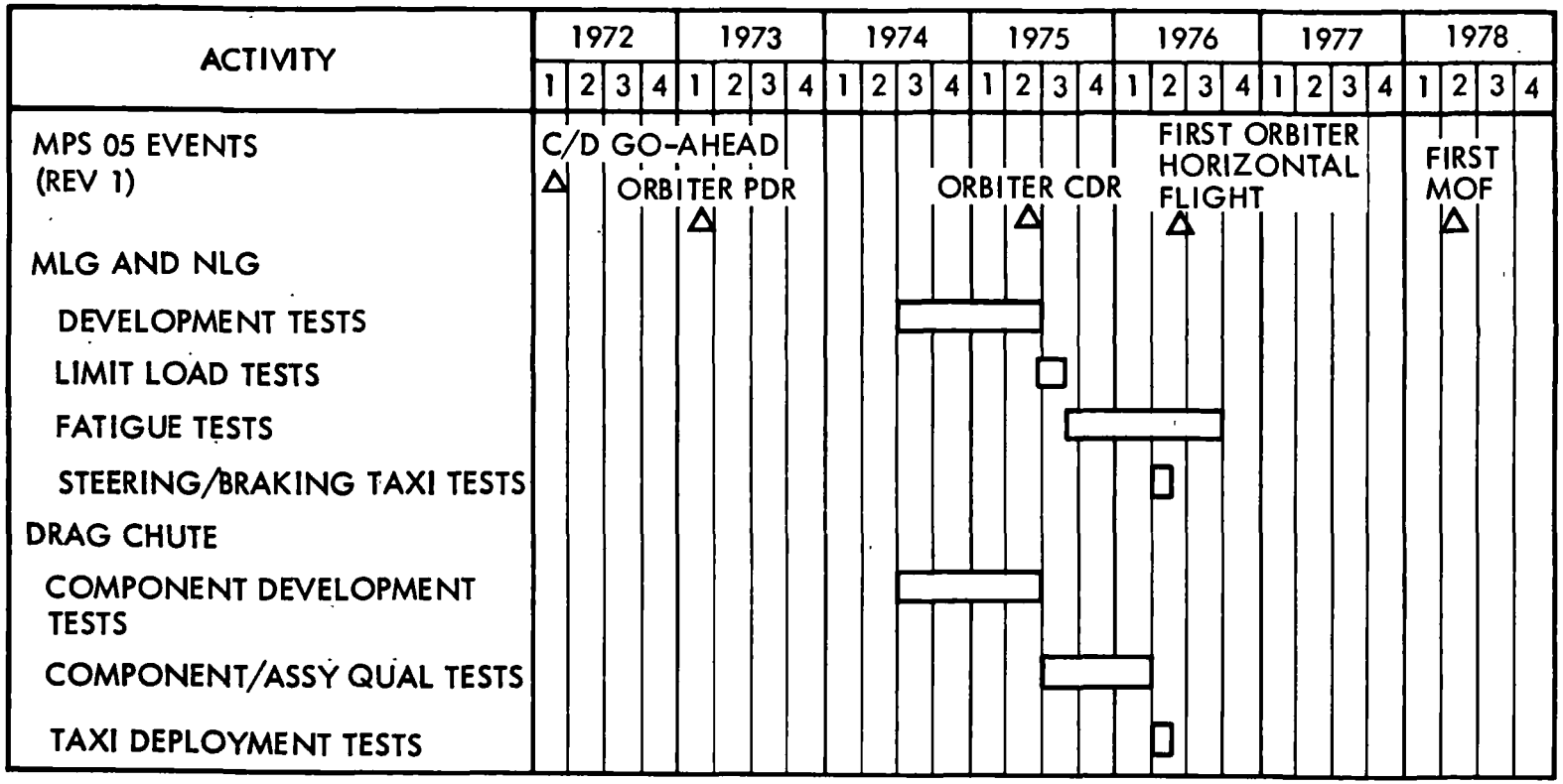


Figure 5-86. Landing Subsystem Test Schedule

Table 5-57. Landing Subsystem Test Hardware Requirements

Assembly	Quantity
Nose landing gear	2.0
Main landing gear	1.0
Deceleration parachute	1.0
Landing gear doors and hydraulic controls	100 percent
Hydraulic power unit	50 percent

Note:

The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.

Table 5-58. Landing Subsystem Test Support Requirements

Area	Requirement
Facilities	Land gear drop test tower Structural test laboratory Area for working mockup of main and nose gear Electrical power - 60 Hz, 3-phase 120V, 440V; 3 phase - 120V; 28vdc
Support equipment	Load application equipment for simulated flight loading of gear and doors Hydraulic power unit Hydraulic servicing unit Digital controller for hydraulic subsystem (To simulate DCM) Load programmer and controls for endurance tests Data acquisition system
Software	Programs to implement the following: Control endurance and life cycle tests Data acquisition/processing/recording Data evaluation
Note: Support requirements cited above are for testing at the major assembly level, and do not reflect requirements for development or qualification of components or subassemblies.	

5.18 DOCKING SUBSYSTEM

5.18.1 Description

The docking subsystem consists of two major assemblies, a docking adapter tunnel and a separation system. Figure 5-87 shows the docking subsystem hierarchy and Figure 5-88 shows the docking subsystem.

The docking adapter tunnel is a loose piece of equipment which may be carried in the cargo compartment or left at the space station. The assembly is made up of a tubular section with docking rings, latches, and interface seals at both ends. It provides a stand-off extension between vehicles at docking and serves as an airlock for IVA crew passage.

The separation system is the mechanism mounted in the orbiter at the docking port. It transmits motion to release the docking latches (mounted in the tunnel adapter) in order to effect undocking and separation.

5.18.2 Requirements

The docking subsystem certification requirements are given in Table 5-59, and have been categorized by method of verification.

5.18.3 Approach and Rationale

The approach and rationale to be used in the development, acceptance, and qualification test program for the docking subsystem is presented in the docking subsystem test logic and constraint network (Figure 5-89).

To support component development and related requirements of the docking subsystem, material and process testing will be performed as required to (1) evaluate, characterize, select, and substantiate the selection of the processing of materials for use in the docking subsystem. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seal, sealant, lubricant, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Compatibility of materials in contact with each other in environments which may result in degradation in properties.

4. Optimization of special welding techniques verified by mechanical and nondestructive tests.

5. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

6. Physical and mechanical properties of shuttle materials that have not been previously established.

7. Joining methods for candidate alloys for shuttle structural and thermal requirements.

Selected elements of the subsystem will undergo thermal-vacuum testing at the component, subassembly, or assembly level. Subsystem and combined subsystem level, ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6.6.

Development tests for the docking subsystem will be conducted utilizing working mockups and breadboard devices to evaluate design concepts of the major mechanical assemblies and systems. A preliminary schedule for testing is given in Figure 5-89. Flight hardware (or representative) will be utilized for complete subsystem qualification and interface tests. Overall vehicle testing is discussed under Payload Deployment.

5.18.4 Test Article Requirements

A test hardware requirements list is given in Table 5-60.

5.18.5 Support Requirements

Developmental testing of docking subsystem design concepts (breadboard and working mockups tests) will be conducted in the Engineering experimental shop area. Most of the qualification testing, other than vendor supplied equipment, will be conducted in-house in the environmental and structural test laboratories. Support requirements are summarized in Table 5-61.

Support Equipment Requirements

Portable GPU equipment will be required to supply hydraulic and electrical power for operational checkout tests of the docking latches.

Software Requirements

Computer software required to support docking subsystem testing included payload manipulation and docking analysis and hard-docked structural loads dynamics analysis.

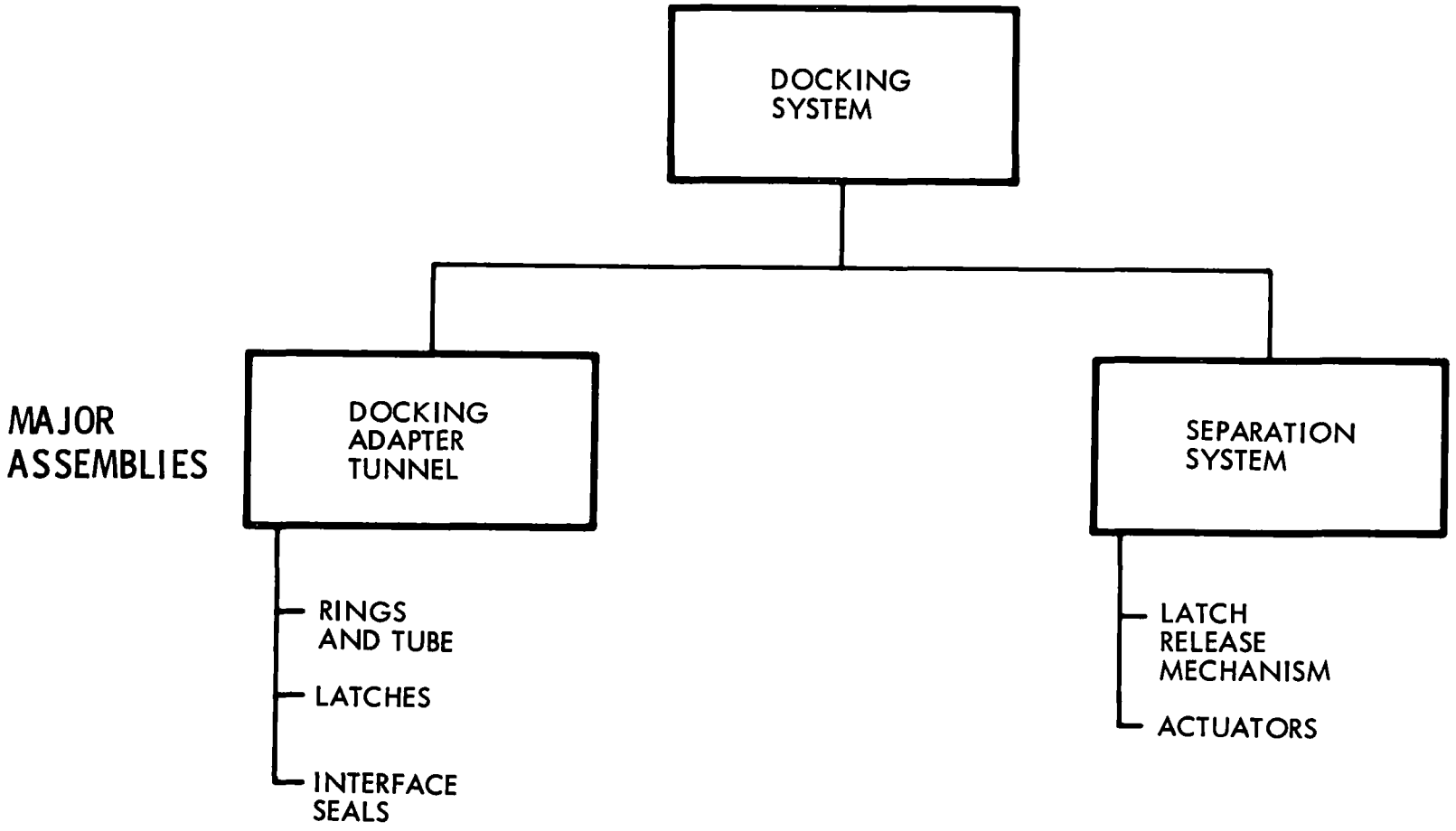


Figure 5-87. Docking Subsystem Elements

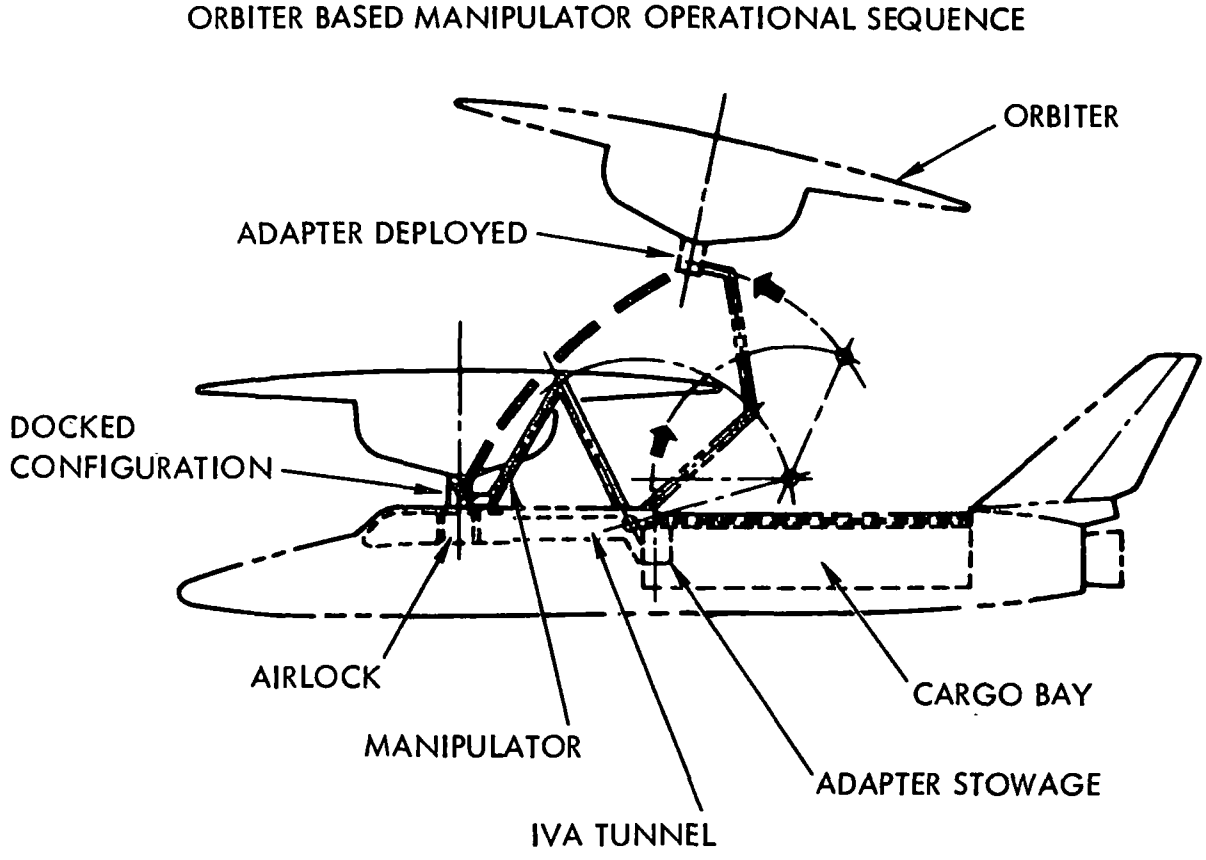


Figure 5-88. Orbiter-to-Orbiter Docking Sequence

Table 5-59. Docking Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
DS ADAPTER TUNNEL							
1. Functional adequacy of docking system including electrical system, latches, docking rings and docking separation system.				S	P		
2. Structural integrity and demonstration of preload adequacy of automatic docking latches after exposure to space environment and docking adapter tunnel.				P			
3. Functional adequacy of interface seals after exposure to space environment.					P		
DS SEPARATION SYSTEM							
1. Functional and structural adequacy of docking latch release mechanism.				S	P		
2. Functional adequacy of latch release actuators after exposure to space environment.			S	P			

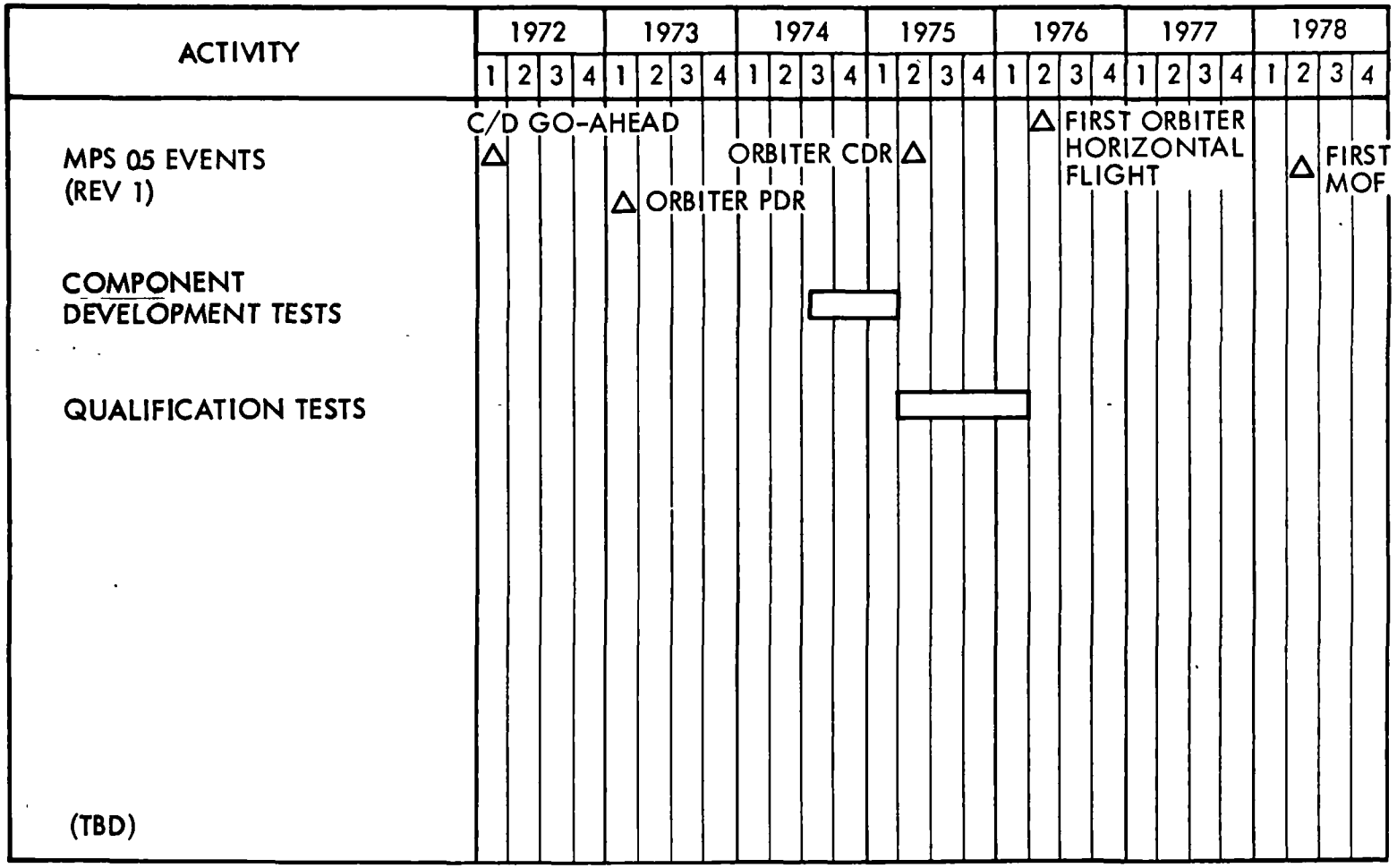


Figure 5-89. Docking Subsystem Test Schedule

Table 5-60. Docking Subsystem Test Hardware Requirements

Assembly	Quantity
Docking adapter tunnel	1
Separation system	1

Note: The hardware quantities identified are for subsystem level testing, and do not include requirements for development or individual components and subassemblies.

Table 5-61. Docking Subsystem Test Support Requirements

Area	Requirement
Facilities	Breadboard and working model test area Structural test laboratory Environmental test laboratory Pressure test cell GN_2 supply/distribution
Support equipment	Hydraulic power unit Test gas distribution/regulation Data acquisition system Miscellaneous environmental test equipment
Software	Programs for evaluation of data

5.19 PAYLOAD DEPLOYMENT AND RETRIEVAL SUBSYSTEM

5.19.1 Description

The payload deployment and retrieval subsystem (PDRS) consists of two manipulator arms, a retractable cargo access tunnel and locks, actuator and controls for payload module, manipulator arms, and a retractable tunnel. Figure 5-90 shows the integrated PDRS hierarchy.

Each manipulator arm is a multijointed, remote-controlled, cargo handling crane. The base of the manipulator is mounted to the orbiter structure. The head mechanism, located at the outer end, mounts the fingers or manipulator tools that attach to the various payload modules, docking tunnel adapter, etc. (Figures 5-91 and 5-92).

The retractable cargo access tunnel provides for IVA transfer between orbiter and payload module. It consists of a telescoping section of tunnel with interface seals, locks, and actuators (Figure 5-93).

The payload retention system consists of the attach fittings and locks for support of the cargo modules during launch, reentry, and landing. Latch release mechanism, actuators, and controls for remote release are provided for deployment (Figure 5-94).

Provisions for stowing the manipulators and the docking tunnel adapter within the cargo compartment will include locks, actuators, and controls for remote release. Provisions for jettisoning a damaged manipulator arm will be incorporated.

5.19.2 Requirements

The PDRS test requirements are shown in Table 5-62 and are categorized by method of verification.

5.19.3 Approach and Rationale

To support component development and related subsequent requirements of the payload deployment and retrieval subsystem, material and process testing will be performed, as required, to evaluate, characterize, select, and substantiate the selection of materials, and processing of materials for

use in the payload deployment and retrieval subsystem. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seal, sealant, lubricant, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time.

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials.

3. Compatibility of materials in contact with each other in environments which may result in degradation in properties.

4. Effects of structural and fluid system corrosion on useful life of critical materials.

5. Optimization of special welding techniques verified by mechanical and nondestructive tests.

6. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials.

7. Physical and mechanical properties of shuttle materials which have not been previously established.

8. Joining methods for candidate alloys for shuttle structural and thermal requirements.

9. Development of materials accelerated life-test methods.

10. Development of fabrication techniques for lightweight tubing systems including minimum bend radius, mechanical joints, heat-treat cycles, and metallurgical joints.

11. Development of composite materials technology (process development and property determination) to achieve significant structural weight savings.

Selected elements of the subsystem will undergo thermal vacuum testing at the component, subassembly, or assembly level. Subsystem and combined subsystem level; ground thermal-vacuum testing is not presently planned. Overall orbiter thermal control test requirements are summarized in Section 6. 6.

Development tests of the manipulator arms, retention mechanism, retractable tunnel and seals will be conducted utilizing working mockups and breadboard devices to evaluate design concepts of the major mechanical assemblies and subsystems.

Subsystems qualification, interfaces, and acceptance tests will be conducted in accordance with performance specifications generated through combined contractor/customer requirements.

The magnitude of testing the complete systems of orbiter vehicle, space station, and payload modules for operations of deployment, retrieval, and docking under simulated zero-g will demand extensive study. Some of the test approaches that will be investigated include:

1. Full-size or scale model, 5 degrees of freedom (gimbal mounted-air bearing support).

2. Full size or scale model, 3 degrees of freedom (air bearing support).

3. Analytical model dynamic analysis.

4. Actual space qualification test (orbital flight).

5. Buoyant suspension.

A preliminary schedule is given on Figure 5-95.

5.19.4 Test Article Requirements

Test hardware requirements are summarized in Table 5-63. Flight hardware (or representative) will be utilized for complete subsystem qualification and interface tests.

5.19.5 Support Requirements

Developmental testing of payload deployment and retrieval subsystem design concepts (breadboard and working mockup tests) will be conducted in the Engineering experimental shop area. Most of the qualification testing, other than vendor supplied equipment, will be conducted in environmental and structural test laboratories. The combined payload manipulation and docking qualification testing may require the use of NASA facilities at MSC or Langley depending upon the test method finally agreed upon.

Portable GPU equipment will be required to supply hydraulic and electrical power for operational checkout tests of the docking latches, manipulator arms, and payload retention locks.

Computer software required to support PDRS testing includes payload manipulation and docking analysis and miscellaneous utility software to support mechanical systems testing. Support requirements are summarized in Table 5-64.

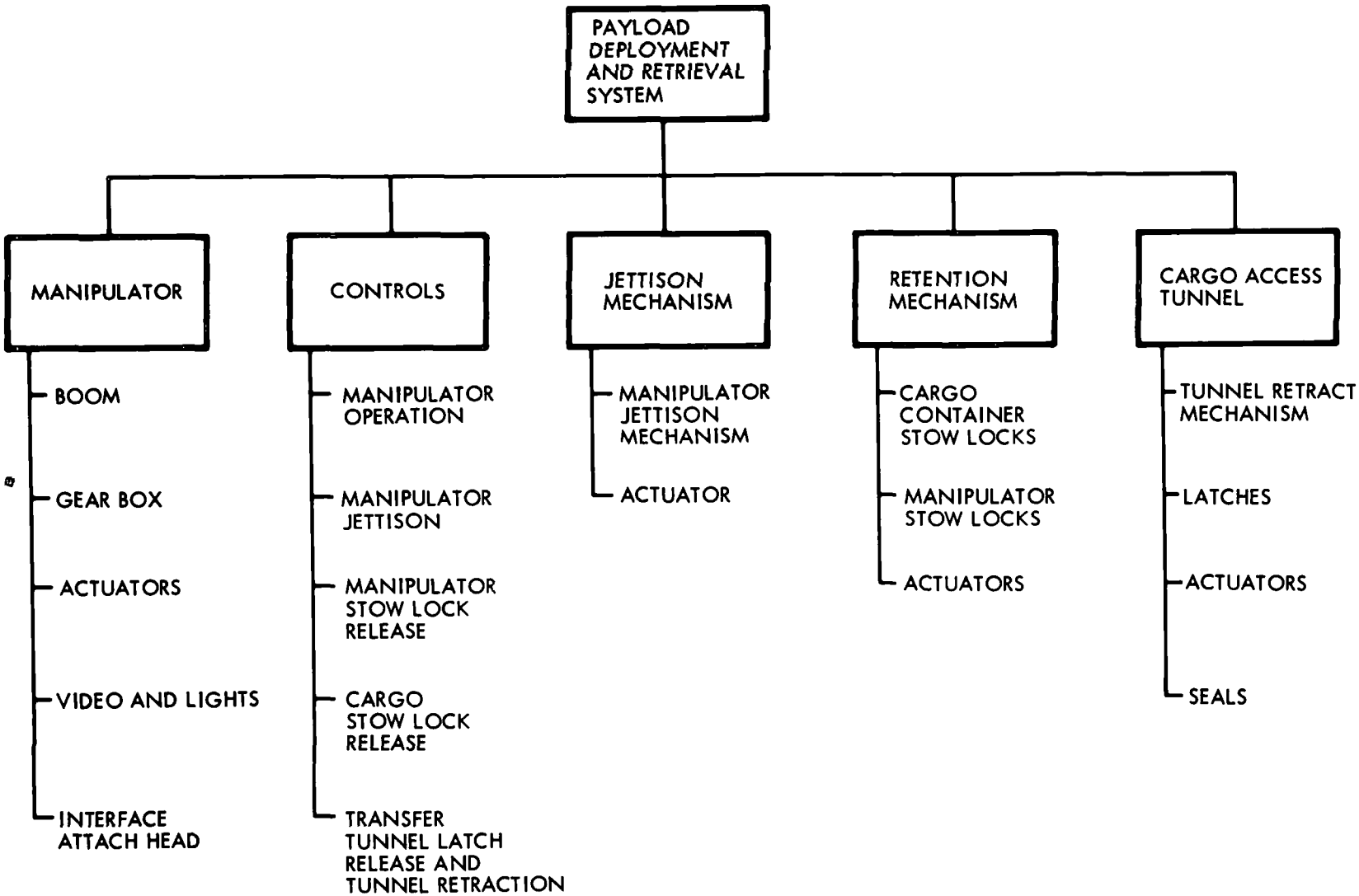


Figure 5-90. Payload Deployment and Retrieval System Elements

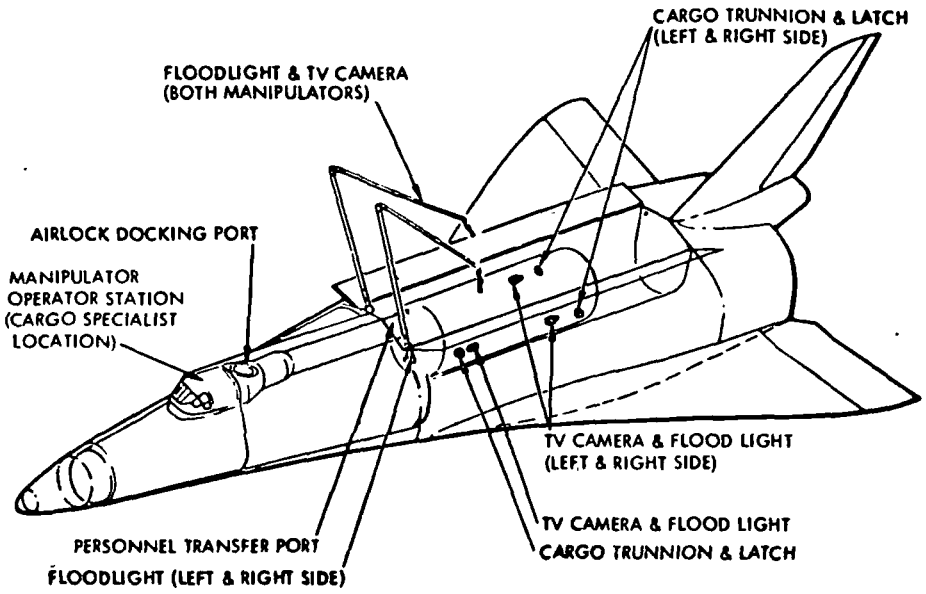


Figure 5-91. Docking and Cargo Handling System

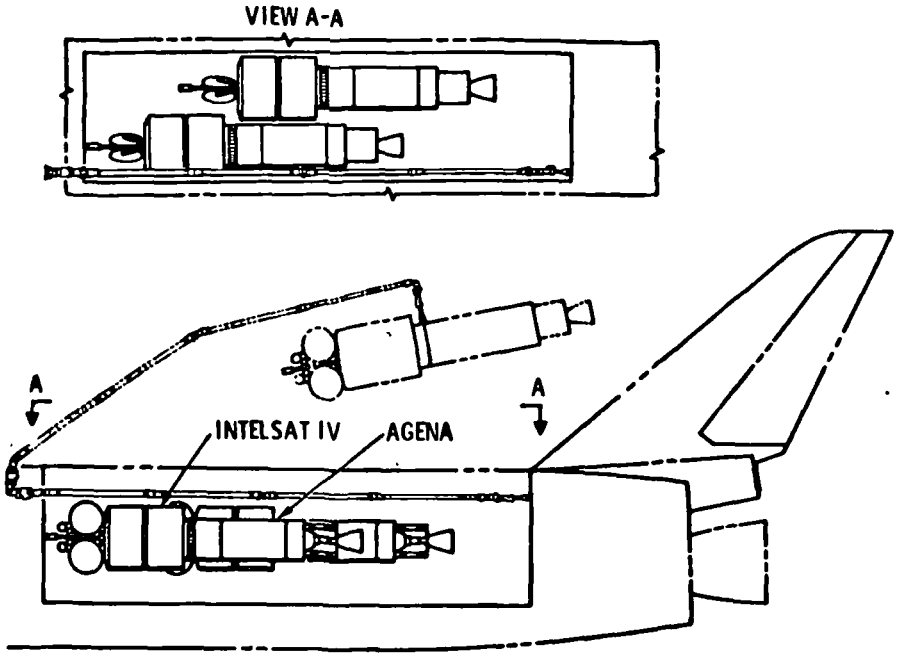


Figure 5-92. Applicability of Manipulator Arms for Deployment and Retrieval

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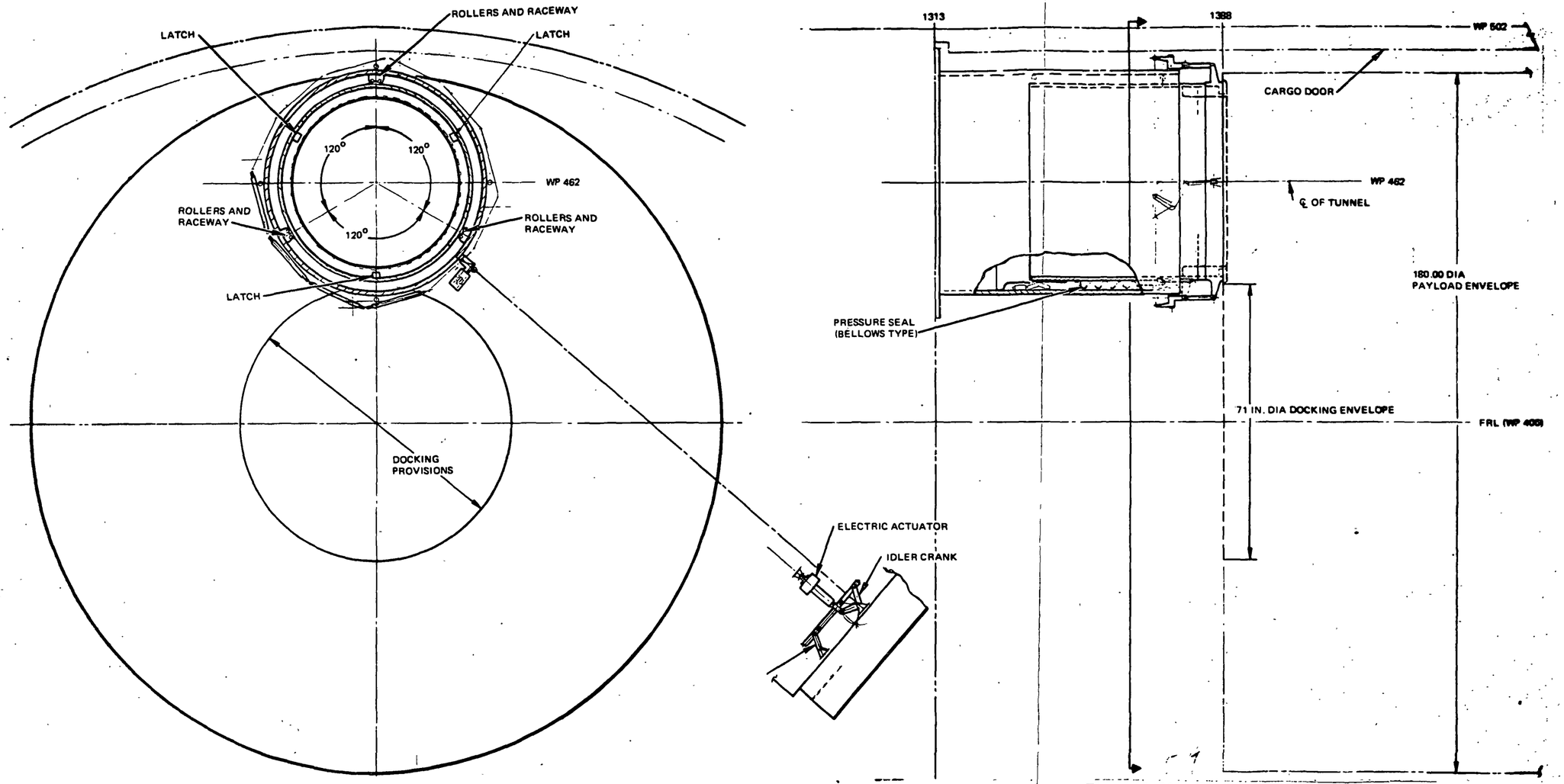


Figure 5-93. Personnel Transfer Port

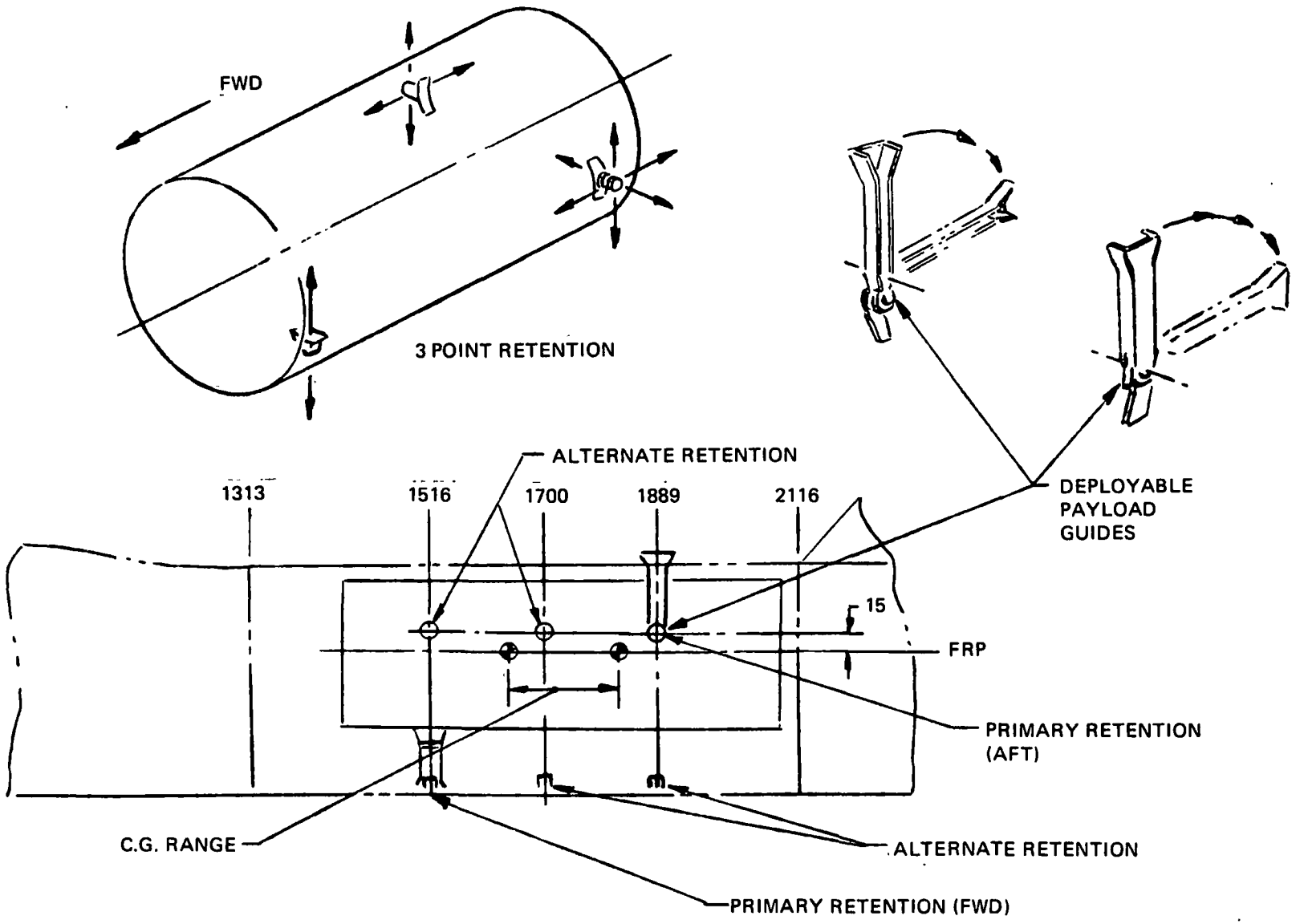


Figure 5-94. Payload Retention

Table 5-62. Payload Deployment and Retrieval Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
PDRS MANIPULATOR							
1. Functional operation of manipulator including control system to perform operations of payload deployment and retrieval and docking manipulation tasks.		S			P		
2. Structural and functional adequacy of boom assemblies, interface attach head, gear boxes, and actuators after exposure to space environment.			S	P			
PDRS CONTROLS							
1. Structural and functional adequacy of control systems for manipulator operation, manipulator jettison, manipulator stowage lock release, cargo stowage lock release, cargo access tunnel latch release, and tunnel retraction				S	P		
2. Functional adequacy of actuators and critical components under applicable thermal and vacuum environment.			S	P			
PDRS JETTISON MECHANISM							
1. Structural and functional adequacy of manipulator jettison mechanisms.				S	P		
2. Functional adequacy of actuators and critical components under applicable thermal and vacuum environment.			S	P			

Table 5-62. Payload Deployment and Retrieval Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
PDRS RETENTION MECHANISM							
1. Functional and structural integrity of stowage lock mechanisms for cargo container and manipulator.			S	P			
2. Functional adequacy of actuators under applicable thermal and vacuum environment.			S	P			
PDRS CARGO ACCESS TUNNEL							
1. Structural and functional adequacy of retractable tunnel and latch mechanisms.				S	P		
2. Functional adequacy of actuators under applicable thermal and vacuum environment.			S	P			
3. Functional adequacy of tunnel and seals by pressure-leakage tests under applicable thermal environment.				S	P		

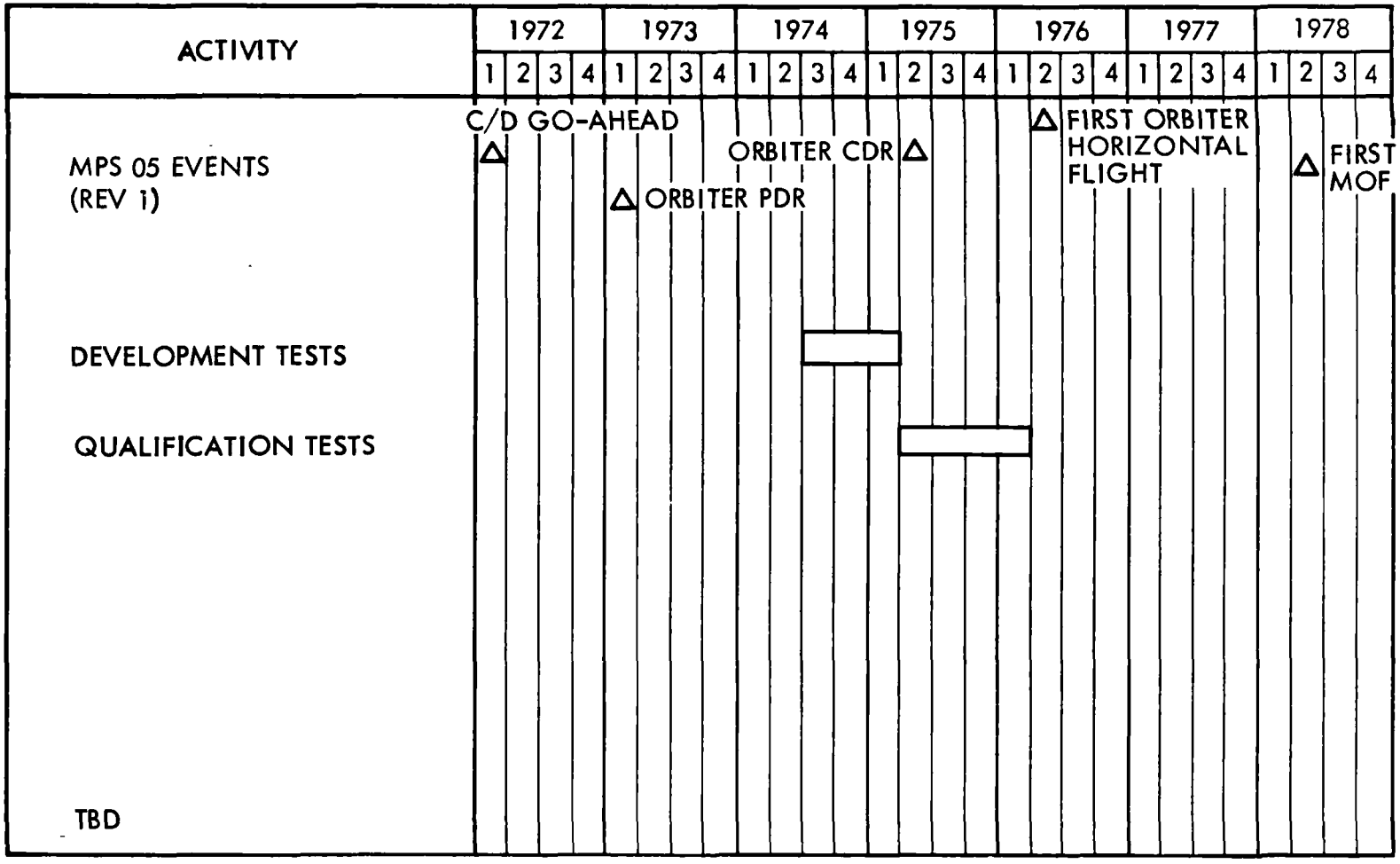


Figure 5-95. Payload Deployment and Retrieval Test Schedule

Table 5-63. Payload Deployment Subsystem Test Hardware Requirements

Assembly	Quantity
Manipulator	1
Controls	1
Jettison mechanism	1
Retention mechanism	1
Cargo access tunnel	1

Note: The hardware quantities identified are for subsystem level testing, and do not include requirements for development/qualification of individual components and subassemblies.

Table 5-64. Payload Deployment and Retrieval Test Support Requirements

Area	Requirement
Facilities	Breadboard and working model test area Structural test laboratory Environmental test laboratory GN_2 supply/distribution
Support equipment	Hydraulic power unit Test gas distribution/regulation Data acquisition system Miscellaneous environmental test equipment
Software	Programs for evaluation of data

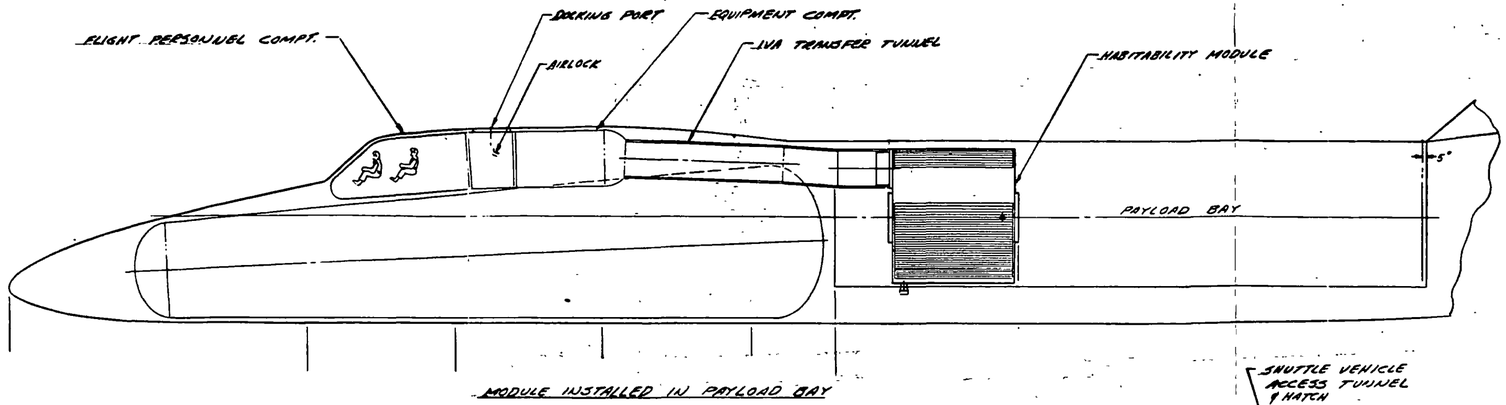
5.20 HABITABLE MODULE

The habitable module, when required, will be located forward in the payload bay with crew and passenger access from the IVA tunnel. Forward and rear access hatches are also provided. The spherical pressure vessel supports the outer cylindrical shell and houses the personnel compartment and the equipment compartment. Since this module may be occupied for an extended period, independent environmental control and life support subsystems, including food and waste management, will be provided in addition to power generation, limited displays, and communication.

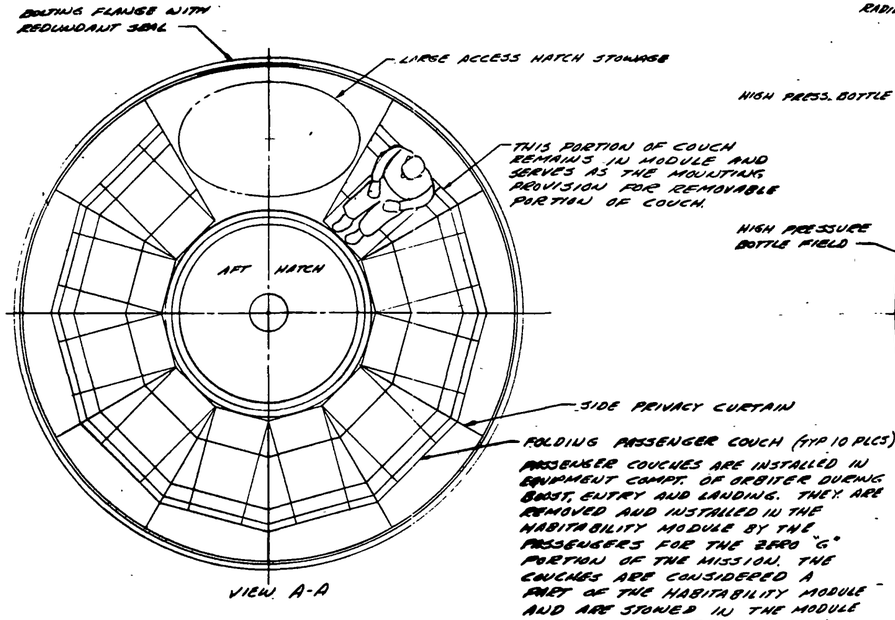
The habitable module structure shown on Figure 5-96 has been designed to produce the lightest possible configuration utilizing conventional materials. A thin-wall aluminum sphere will be foam-stiffened and fabricated in two hemispheres for manufacturing simplicity. Each hemisphere will be fabricated by the high-energy-forming technique from a welded gore array. A docking port is provided at each end of the module for maximum flexibility of module usage. A tunnel and hatch provide access from and an extension of the orbiter IVA tunnel when the module is in the cargo bay. A flat honeycomb transverse floor with a center passage is affixed to an internal flange of one of the hemispheres.

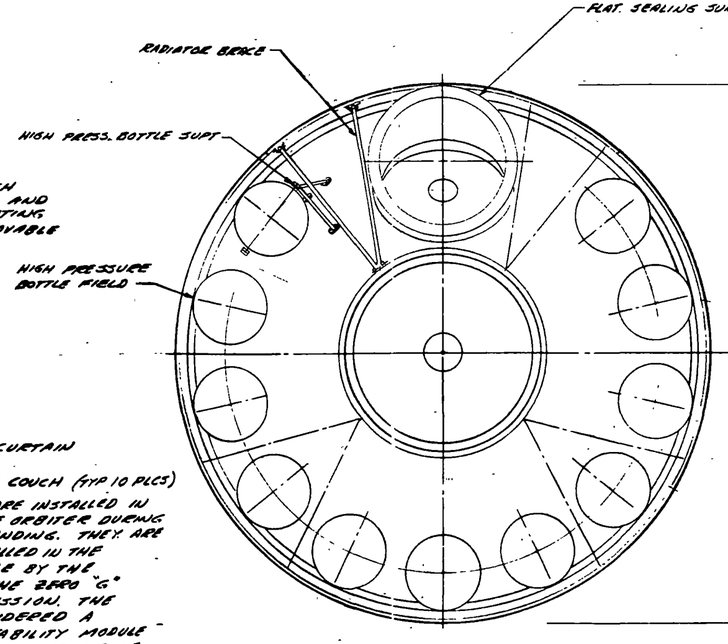
The IVA tunnel interface hatch hinges inward, and the two docking port hatches ride on rails and slide into the module for stowing.

Test requirements for the ECLS, structure, power generation, etc., will be similar to those itemized elsewhere in this volume. Test hardware, logic and constraints, schedule and support requirements have not been defined for the habitable module.



MODULE INSTALLED IN PAYLOAD BAY





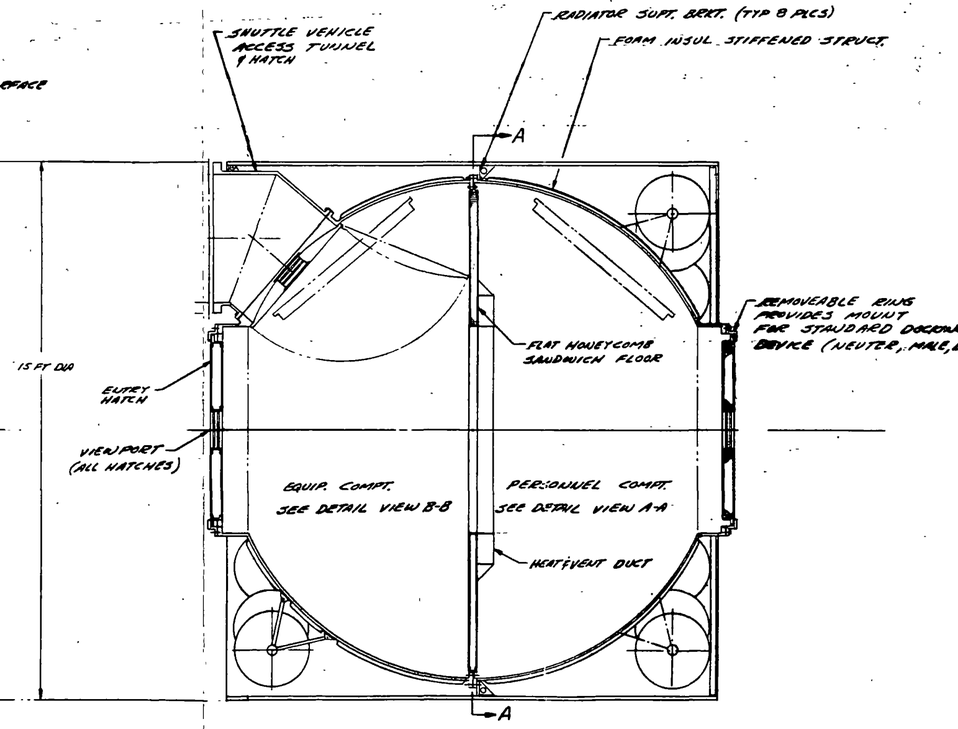


Figure 5-96. Habitable Module Structure

6.0 COMBINED SUBSYSTEM TESTS

This section describes two categories of testing activity. The first category relates to those tests which involve multiple subsystem operation and, in accordance with the work breakdown structure, are designated as combined subsystem tests. Included in this category are the following test programs:

1. MPS cluster static firing test program
2. Avionics subsystem integration laboratory test program
3. ECLSS crew cabin test program
4. Auxiliary propulsion test program

The second category includes the testing which is oriented toward a discipline or technology rather than specific subsystem. Included in this category are the following test programs:

1. Wind tunnel test program
2. Thermal control test program
3. Electromagnetic compatibility test program
4. Structural dynamics test program

An individual subsection is provided for each of the combined subsystem tests. Included is an identification of the basic operations, test requirements, approach and rationale, test article configurations, schedule, facility requirements, and support equipment.

It may be noted that the requirements indicated for the combined subsystem tests are also identified for the respective subsystems in Section 5.0. The tabulations presented in Section 5.0 represent the total certification requirements for each subsystem. The listings in this section provide a composite of the subsystem requirements to be satisfied during the combined subsystem testing.

The current orbiter test program baseline does not include a dedicated vehicle for verifying overall subsystem performance under simulated space

conditions. However, crew-cabin environmental control tests under ambient conditions as well as thermal-vacuum tests of major vehicle sections are planned. Consideration is being given to employing a complete crew and passenger compartment and avionics bay for thermal-vacuum tests in the MSC environmental chamber.

Unless specifically noted, the test article hardware, facilities, and support equipment defined for each of the combined subsystem tests represent additional requirements from those established for subsystem tests in Section 5. 0.

6.1 CLUSTER FIRING PROGRAM

6.1.1 Configuration

The orbiter cluster firing test vehicle will consist of the following major vehicle assembly: the integral LH_2 tank, the midbody structure with the main LO_2 tanks, the main engine compartment, the main engines, the propellant feed ducts, and pressurization system. At the conclusion of the static firing program, this assembly will be returned to the fabrication site for refurbishment and modification as required prior to being assembled in Orbiter 5. Partial avionics and thrust vector control subsystems will be installed as required for instrumentation, control, checkout and engine gimbaling. Thermal control subsystem hardware will also be required in support of the cluster static firing. Figure 6-1 is a block diagram of the cluster firing test vehicle subsystems and components.

6.1.2 Operations

The orbiter cluster firing test vehicle block flow diagram is depicted in Figure 6-2.

6.1.3 Requirements

The orbiter cluster firing test program requirements are listed by subsystem in Table 6-1.

6.1.4 Approach and Rationale

The primary issue to be resolved by the MPS cluster firing program is the basic compatibility of all MPS components/assemblies as well as MPS compatibility with interfacing subsystem elements. Included in the subsystem interfaces is the TCS vehicle purge, which will be verified before and during the cluster firing program. This verification will take place in conjunction with propellant tanking/detanking/safing operations. Details on the TCS purge test program are provided in Section 6.6.

An evaluation was conducted to verify the necessity for a static firing program on the orbiter main propulsion subsystem. Specific requirements associated with each assembly were evaluated to determine if this requirement could be economically fulfilled by other test techniques. This evaluation revealed many critical objectives that could only be satisfied by static firing tests. The objectives are summarized below:

1. Pressurization
    a. Initial characteristics with small ullage
    b. Stratification due to pressurization
    c. Engine power level (EPL) effects on pressurization

d. Single engine out/EPL during the critical period near cutoff

e. Heat exchanger stability at low thrust and engine mixture ratio

2. Structure

a. Compliance (single engine, dual engine, EPL)

b. Structural/modal characteristics under various engine operating conditions

c. Stability characteristics

d. Determination of thrust structure critical load paths

3. Engine

a. Start and shutdown transient characteristics influences

b. Base heating with/without engine out

c. Propellant utilization (PU) characteristics

d. Determination of vibration sensitive areas

e. Stratification effect on performance

4. Propellant utilization

a. Determination of propellant load/off-load constraints

b. Determination of PU performance during static firing

5. TVC

a. Performance requirements under standby conditions

b. Phase/lag and acceleration rates

c. Start transient controllability

d. Maximum loads encountered

6. Avionics

   a. Evaluation of onboard checkout and monitoring sensor performance and adequacy.

   b. Evaluation of sensor signal conditioning performance

   c. Evaluation of sensor signal conditioning to data bus to ACT interfaces

   d. Evaluation of computer signal to ACT interface (utilize ground computer in place of flight computer)

   e. Evaluation of software programs

7. Propellant feed

   a. Capability of recirculating system and insulation to provide conditioned propellants at engine inlets at start and through thrust build-up

   b. Propellant flow characteristics at EPL and throughout the throttle range

   c. Evaluation of propellant feed system dynamic characteristics

8. Operations

   a. Development of operational checkout, servicing, and maintenance procedures

   b. Support equipment and facility support requirements

   c. Development of operational test procedures

9. Insulation

   a. Evaluation of structural characteristics of insulation

   b. Evaluation of thermal characteristics and thermal efficiency (boil-off, stratification, etc.)

As a result of tradeoffs, it was considered most cost/schedule effective for the static firing test program to be conducted on a modified LUT at Launch Complex 39, KSC. The static firing program on the orbiter is scheduled to be performed concurrently with the booster static firing program, and both

programs are to conclude prior to the delivery of the first vertical flight test vehicles.

Figure 6-3 is a preliminary main propulsion system development schedule and includes the cluster firing program.

6.1.5 Test Article Requirements

Test hardware requirements are given in Table 6-2.

6.1.6 Support Requirements

The major support requirements for the cluster firing program are listed in Table 6-3 (Requirements for the TCS testing, performed on the cluster static firing test article during approximately the same time period are given in Section 6.6).

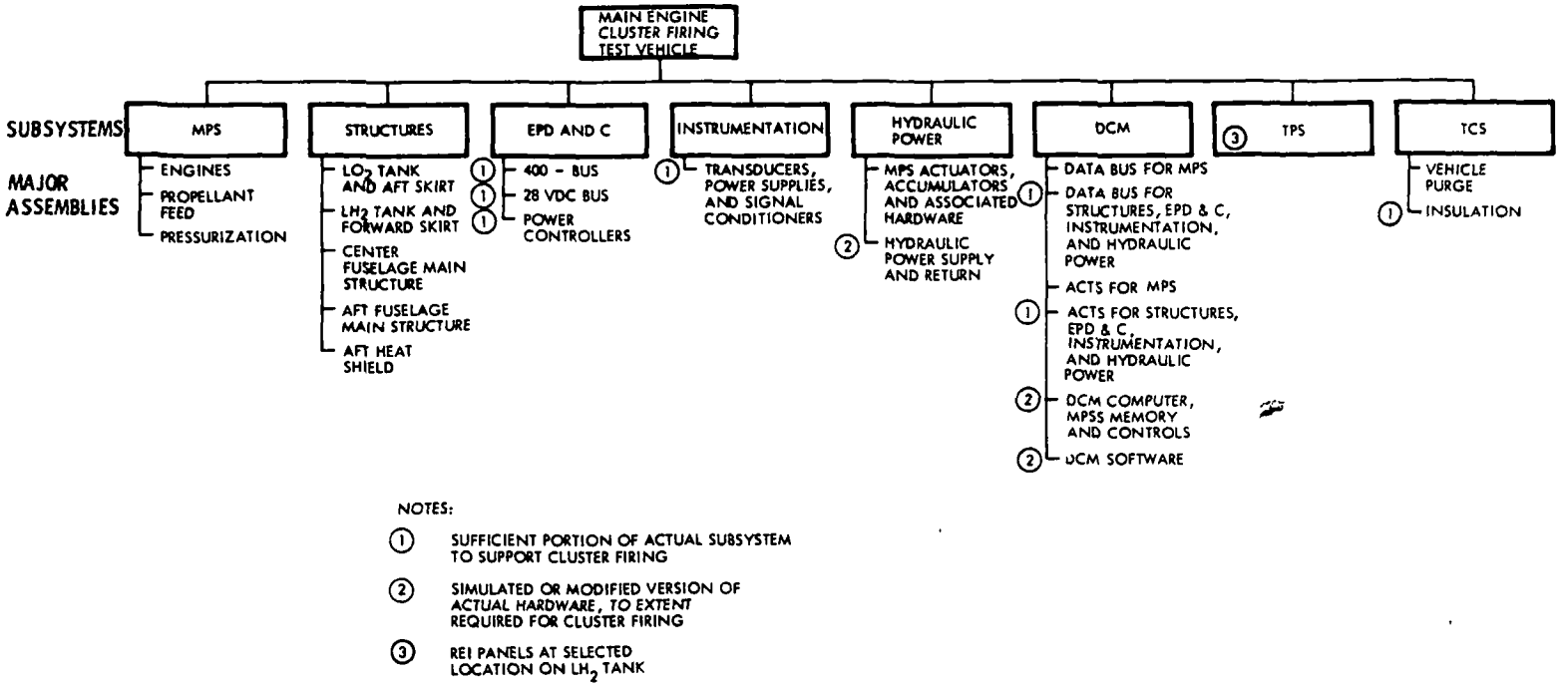


Figure 6-1. Test Vehicle Configuration Elements

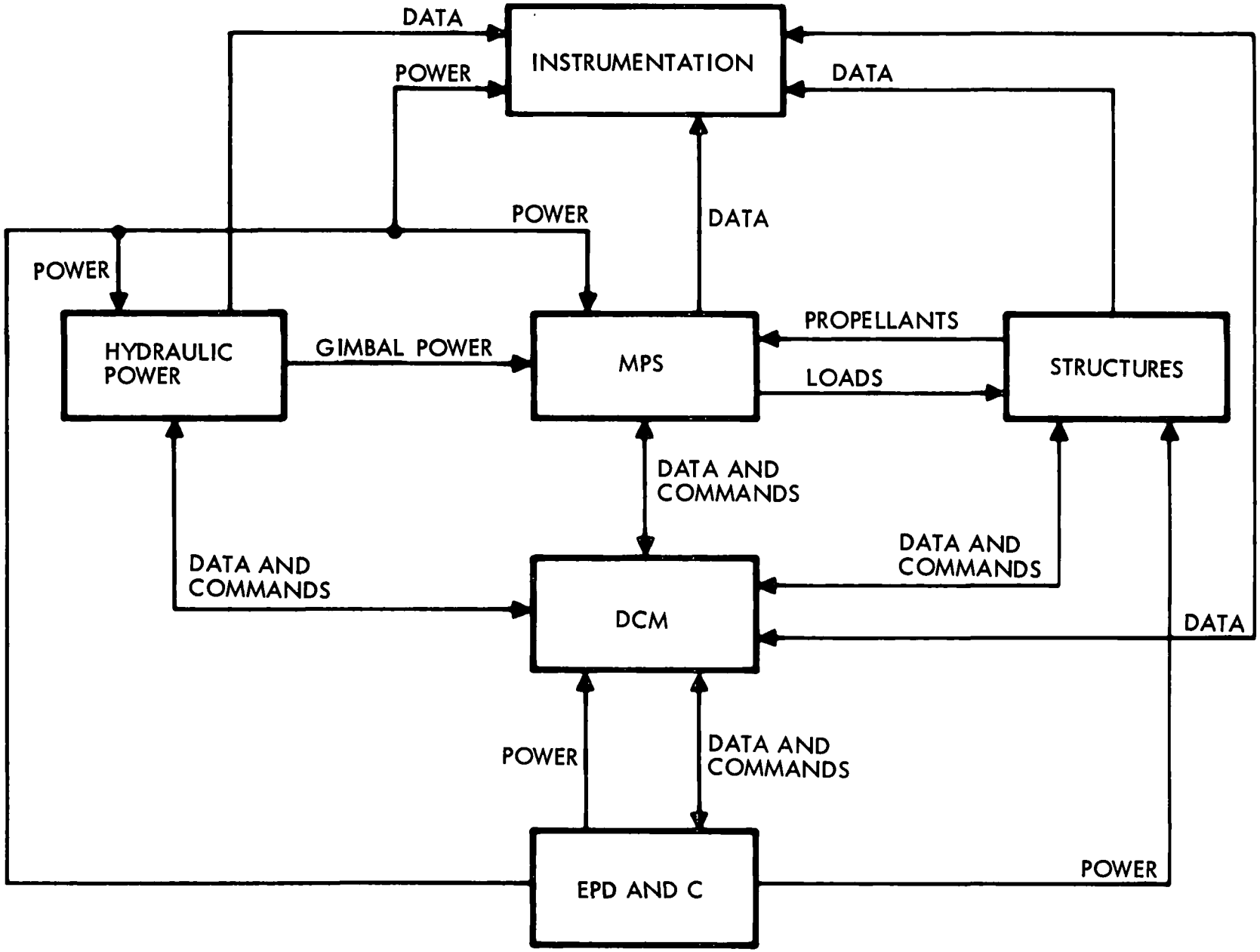


Figure 6-2. Main Engine Cluster Firing Schematic

Table 6-1. Cluster Firing Program Combined Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
MPS OPERATIONAL REQUIREMENT							
1. Compatibility of all MPS components/assemblies.						P	
2. Accessibility of components in mated and horizontal modes.						S	
3. Ability to horizontally change engines.						S	
4. Ability of main propulsion subsystem to operate in one-engine-out malfunction mode.						P	
5. Engine and engine compartment components ability to withstand acoustic and vibration effects.						P	
6. Adequacy of base heating thermal protection for engine and engine compartment components.						P	
7. Ability to safe the main propulsion subsystem						P	
MPS ENGINE REQUIREMENTS							
1. Capability to leak check engine/orbiter interfaces.						P	
2. Functional capability of propellant depletion/engine cutoff sequence.						P	
3. Capability of engine/vehicle Pogo suppression.						P	
4. Capability to throttle engines over entire range (50 percent to 109 percent).						P	
5. Adequacy of engine thrust vector control (TVC) attach points to withstand loads.						P	
6. Ability to dry gimbal with sufficient clearance.						P	
7. Capability to dry gimbal engines in horizontal position.						P	

Table 6-1. Cluster Firing Program Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
8. Capability to gimbal engines over angular rate and response range.						P	
9. Capability of main propulsion subsystem to supply the engine with required GN_2, GHe, electrical, and hydraulic, services per engine ICD requirements.						P	
10. Determination of effects of propellant stratification on engine performance.						P	
PROPELLANT TANK AND FEED ASSEMBLY							
1. Ability to purge propellant tanks and feed lines.						P	
2. Ability to provide propellants to engine under all operating conditions.						P	
3. Capability of pre-valves to vent trapped propellant in engine back into tanks						P	
4. Results of propellant stratification on propellant residuals.						P	
5. Boil-off rates of main propulsion subsystem.						P	
6. Engine heat leak rate.						P	
7. Determination of ability to maintain minimum required NPSH resulting from vehicle induced stratification combined with propellant draw-down characteristics.						P	
PRESSURIZATION ASSEMBLY							
1. Capability to inert pressurization assembly						P	
2. Ability of vent valves to maintain tank pressure in flight						P	
3. Capability of pressurization assembly to provide required pressurizing gas to propellant tanks under all conditions.						P	

Table 6-1. Cluster Firing Program Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
4. Capability of prepressurization assembly to provide adequate tank pressure through boost phase.						P	
PROPELLANT UTILIZATION (PU) ASSEMBLY							
1. Compatibility of propellant quantity gaging system with propellant tanks.						P	
2. Adequacy of point sensor and capacitance probes to control propellant loading.						P	
3. Ability of propellant utilization assembly to limit residuals at engine cutoff.						P	
4. Compatibility of capacitance probes and point sensors with vehicle IAS.						P	
MISCELLANEOUS							
1. Ability of propellant recirculation assembly to condition the propellant feed lines and engines prior to engine start.						P	
2. Compatibility of propulsion subsystem with COFI						P	
3. Compatibility of propulsion subsystem with instrumentation						P	
4. Acceptability of simultaneous LO_2 and LH_2 servicing						P	
5. Compatibility of propulsion subsystem with SE						P	
6. Capability to off-load propellant at acceptable rates.						P	
7. Ability to vent ullage pressure through vehicle ground vent						P	
8. Ability to safe engine						P	
9. Ability to maintain positive tank pressure during ground operations.						P	

Table 6-1. Cluster Firing Program Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
HYDRAULIC POWER							
1. Ability of hydraulic power subsystem to provide sufficient output to support mission requirements.						P	
2. Compatibility of hydraulic power actuators and main engines under operating environment.						P	
DATA AND CONTROLS MANAGEMENT							
1. DCM ability to perform COFI						P	
2. Functional interface between DCM and main propulsion subsystem						P	
3. TVC compatibility with engine start transients						P	
4. TVC compatibility with the maximum loads encountered						P	
5. TVC phase lag and acceleration rates						P	
6. Performance requirements under standby conditions						P	
STRUCTURES							
1. Determination of structural modal characteristics under various engine operating conditions						P	
2. Structural stability characteristics						P	
3. Determination of structural compliance (single engine, dual engine, EPL)						P	
4. Structural integrity of slosh and antivortex baffles during fill, drain, and engine feed modes.						P	
EPD&C							
1. Compatibility of power controllers with their MPS interfaces.						P	

Table 6-1. Cluster Firing Program Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
INSTRUMENTATION (DFI AND OPERATIONAL)							
1. Compatibility of transducers and signal conditioners with their MPS and structures interfaces.						P	
2. Compatibility of transducers and signal conditioners with their ACT interfaces.						P	

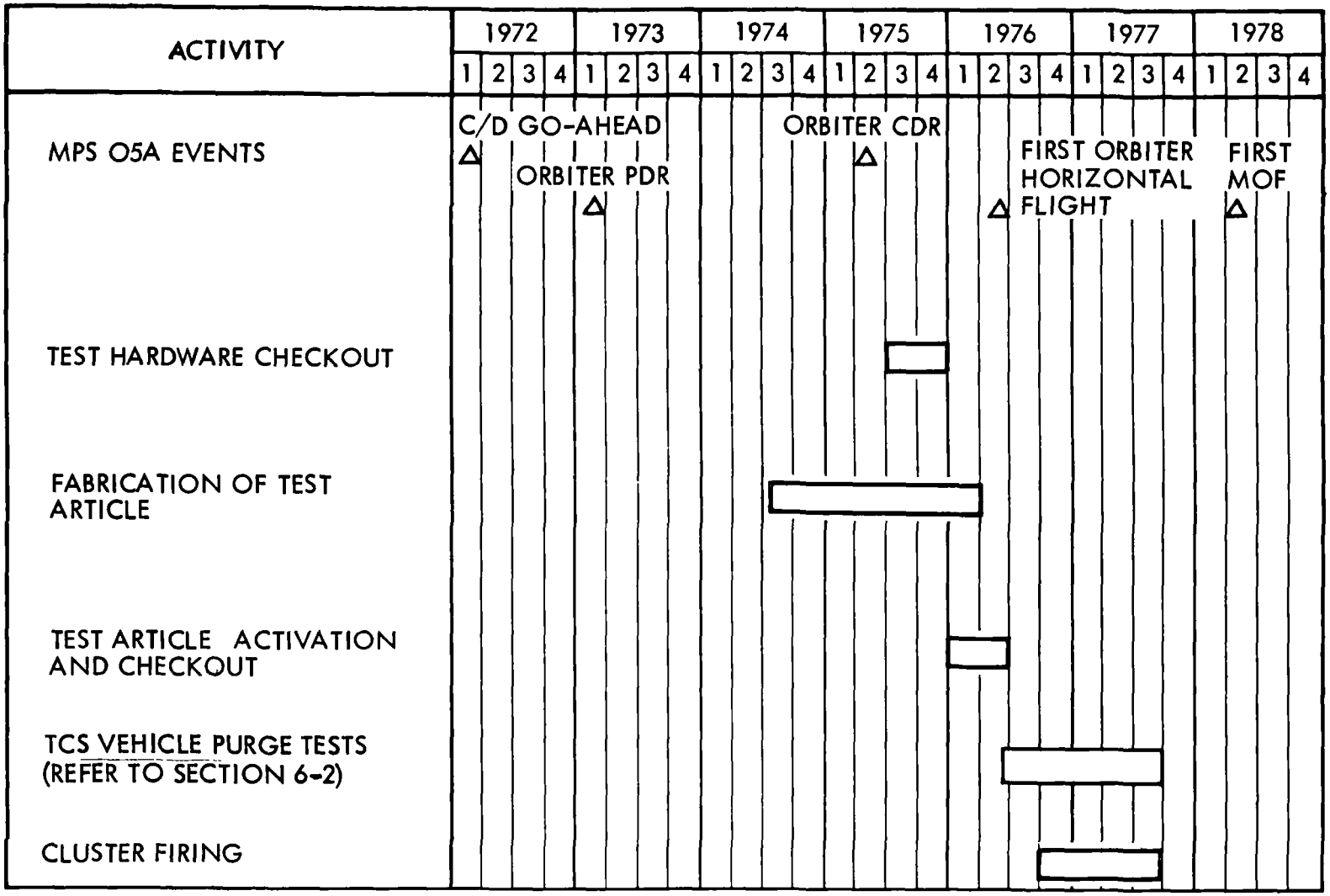


Figure 6-3. MPS Cluster Firing Test Schedule

Table 6-2. Main Engine Cluster Firing Test Hardware Requirements

Subsystem	Assembly	Quantity
MPS	Engines	2
	Propellant feed	100 percent
	Pressurization	100 percent
Body structure	LO_2 tank and aft skirt	1
	LH_2 tank and fwd skirt	1
	Center fuselage main structure	1
	Aft fuselage main structure	1
	Aft heat shield	1
Hydraulic power	MPS actuation	100 percent
	Fluid distribution	20 percent
	Hydraulic power generation assembly	2
EPD&C	400 Hz bus	20 percent
	28 vdc bus	20 percent
	Power controllers	10 percent
Instrumentation	Transducers, power supplies, signal conditioners	5 percent
DCM	Data bus harness	10 percent
	ACT assemblies	10 percent
	DMC	1
	Mass memory	1

Table 6-3. Main Engine Cluster Firing Test Support Requirements

Area	Requirement
Facility	Launch umbilical tower Launch pad LH_2 storage/transfer LO_2 storage/transfer GN_2 storage/transfer He storage/transfer H_2 disposal Water: Firex, flame deflector cooling, potable Test control room Electrical power: 60 cycle 3 phase - 120 v, 440 v; 400 cycle 3 phase - 120 v; 28 vdc Flame deflector
Support equipment	Static firing support structure Hydraulic servicing Hydraulic power Test gas regulation/distribution system Control/simulation/data acquisition computing capability Test control consoles Electrical power distribution Miscellaneous engine support/servicing equipment Altitude simulation aspirators Thrust measuring system
Software programs	Control of test sequence (to include securing and safing in the event of abort) Simulation of DCM and G/N&C Data acquisition Test reporting Provide CRT display of test data Data analysis

6.2 AVIONICS/NONAVIONICS TEST PROGRAM

6.2.1 Configuration

Orbiter avionics integration will be accomplished in the Avionics Subsystem Integration Laboratory (ASIL). The ASIL will include (1) the data and controls management subsystem (DCM) with applicable flight and special purpose software, (2) the guidance navigation and control subsystem (GN&C) with the inertial measurement unit (IMU) mounted on a dynamic motion table, and the capability to interface with the hydraulics/controls laboratory for end-to-end flight controls testing, (3) the communications subsystem (COMM) with artificial stimuli of the navigation and landing aids, (4) the displays and controls (D&C) subsystem installed in a flight deck mockup with dynamic visual presentations of the landing function, the star tracking function, and the docking function, (5) the electrical power distribution and control subsystem (EPD&C) with simulations of all actual power sources and selected nonavionics loads and (6) the development flight instrumentation (DFI) subsystem with simulated inputs. To facilitate DCM, software, COFI, and D&C evaluations, computer and/or other simulations of selected portions of nonavionics subsystems and payload interfaces will be available. Figure 6-4 represents the ASIL configuration.

6.2.2 Operations

A functional block diagram of the orbiter subsystems within the ASIL is depicted in Figure 6-5.

6.2.3 Requirements

The orbiter ASIL test requirements are listed in Table 6-4 and are categorized as follows:

1. DCM-D&C integration requirements
2. Avionics integration requirements
3. Avionics/Nonavionics integration requirements

6.2.4 Approach and Rationale

The data and controls management (DCM) subsystem acts as the integrating agent for all vehicle subsystems. It is also a hardware-minimized subsystem which requires a significant amount of software to function. Considering these two facts, it appears that a test article is required where the

many hardware-to-hardware and hardware-to-software interfaces can be validated. Alternative test articles considered were:

1. An all systems in-house test vehicle.

2. A boilerplate type of vehicle inclusive of all avionics and selected nonavionics subsystems.

3. Performance of all integration on the first production vehicle (FTV 1).

4. A laboratory where the actual avionics elements and the software could be interfaced and integrated. Due to the lesser complexity of the avionics/nonavionics interfaces, it was determined that the nonavionics interfaces could be simulated (computer or hardware), with the exception of the flight control hydraulics, actuators, etc.

Alternative four, which is known as the ASIL (avionics subsystem integration laboratory), was selected because it enables greater test configuration flexibility, minimizes production schedule risks due to software/hardware interface problems, and should be less costly than alternates one or two. ASIL will also provide a continuing tool for development and evaluation of software and hardware modifications and provide the capability for evaluation of production avionics LRU's.

The ASIL activity will begin with the integration of the DCM central processing unit (CPU) with the mass memory, data bus, and software. Next, the integrated displays and controls (ID&C), which is a primary input/output device for the DCM, will be interfaced with the DCM. Two-way information transfer between the ID&C and the DCM will be verified. During the period that the DCM is being developed, other avionics subsystems will be undergoing their respective development and preparation for interfacing with the DCM. To minimize test hardware requirements, it is expected that the subsystem development task and avionics integrating task will utilize common hardware. Interface testing between the DCM and the other avionics elements will enable validation of redundancy management techniques, onboard checkout techniques, adequacy of sampling rates, subsystem management techniques, and the associated software.

Measurement of the flight controls end-to-end system characteristics will be facilitated by interfacing the ASIL with the hydraulics/control laboratory, which will include prime movers, hydraulics, actuators, inertia simulators, and aerodynamic load simulations as required. The combined

test articles will be used to develop software and to support analysis of control system stability. Testing will permit development of phase relationships between control system forcing functions and vehicle structural bending modes. This will include analysis of structural deflection between wing and elevon, vertical fin and rudder, and thrust vector controls and thrust bulkheads. Elasticity of these structural elements will be duplicated, to the extent feasible, on the test article.

Evaluation of the flight control system with the man-in-the-loop will be accomplished via a flight deck mockup with external visual presentations for simulation of critical mission phases. A computer will close the loop between the flight controls and the visual presentations. This will enable pilot evaluation of controls, flight control system gains, gain transitions, and the resulting transients. The dynamic simulation provided will also enable pilot evaluation of CRT and message panel displays and formats.

Figure 6-6 is a preliminary ASIL test program schedule.

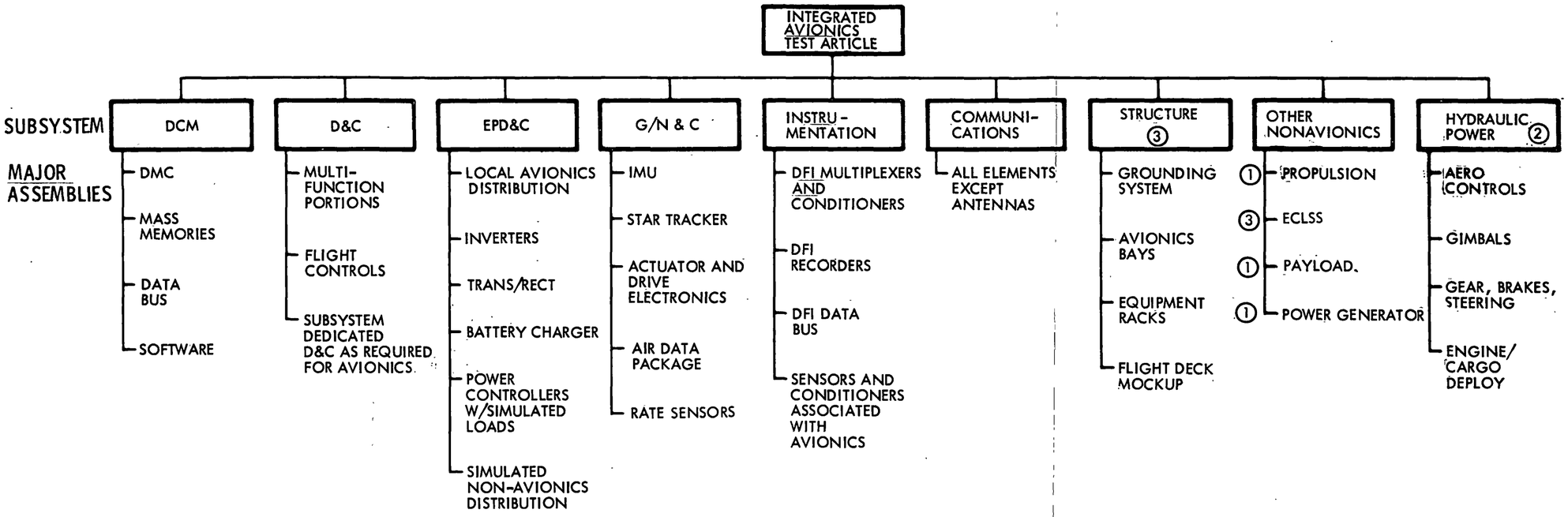
6.2.5 Test Article Requirements

Test hardware is listed in Table 6-5.

6.2.6 Support Requirements

The major support equipment requirements, facility requirements and software are listed in Table 6-6.

LEVELS



NOTES:

① COMPUTER OR HARDWARE SIMULATION

② COMPUTER SIMULATION AND HYDRAULIC POWER LABORATORY

③ PARTIAL COMPUTER SIMULATION AND PARTIAL ACTUAL HARDWARE

Figure 6-4. Avionics Subsystems Integration Laboratory Configuration Elements

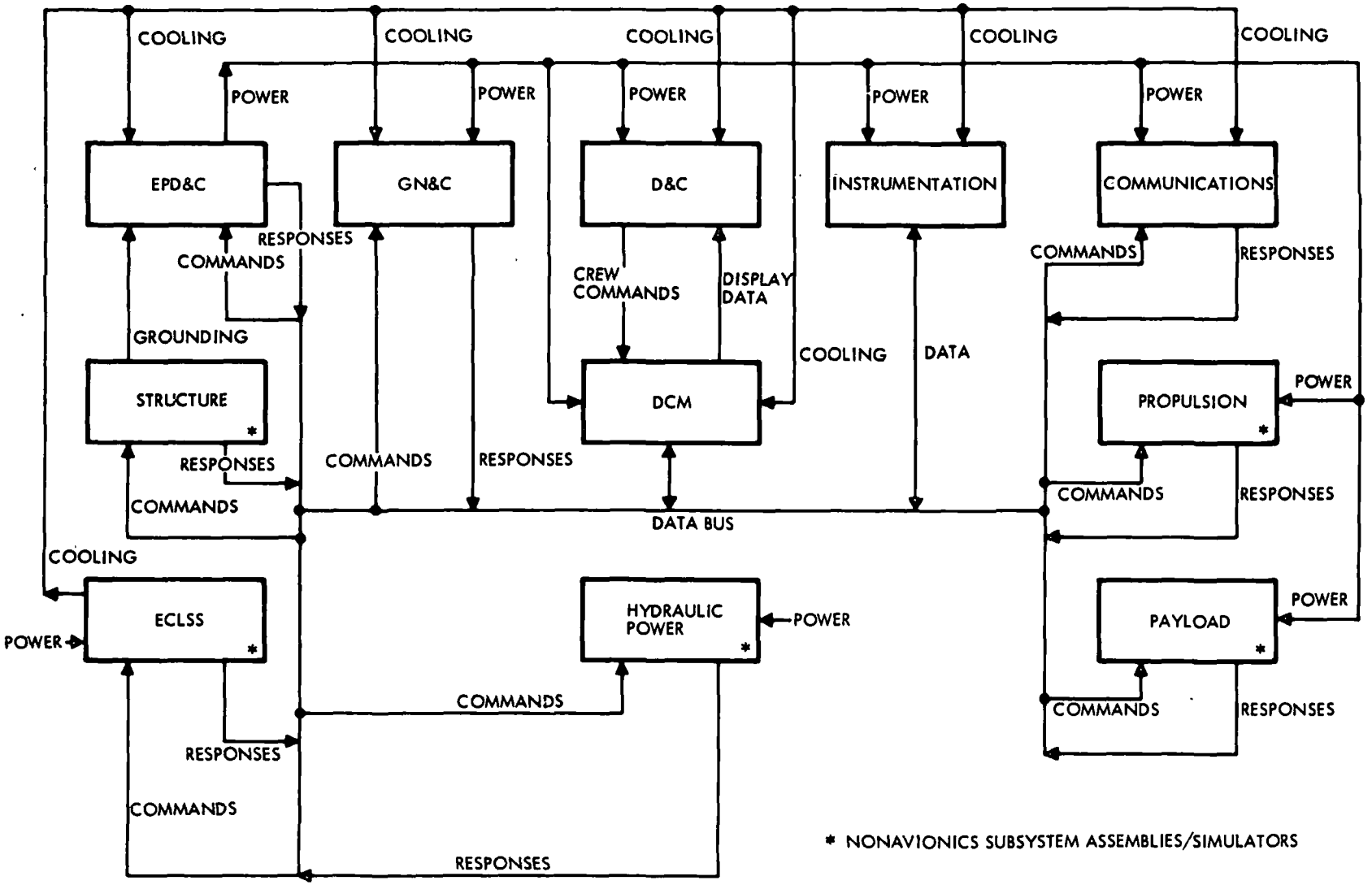


Figure 6-5. ASIL Schematic

Table 6-4. Avionics Subsystem Integration Laboratory Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
DCM/D&C INTEGRATION REQUIREMENTS							
1. Ability to control DCM with displays and controls.						P	
2. Ability of displays and controls to interrogate and display DCM registers.						P	
3. Ability of D&C to display subsystem type data provided by the DCM.						P	
AVIONICS INTEGRATION REQUIREMENTS							
1. Ability of D&C to provide satisfactory GN&C, COMM, instrumentation, and EPD&C subsystem control and display capability.						P	
2. Ability of the caution and warning (C&W) function to identify critical failures and provide crew alert.						P	
3. Adequacy of subsystem information display schemes.						P	
4. Evaluation of compatibility of flight controls with the flight control system gains during all flight modes.						P	
5. Ability of crew overrides to alter flight modes and sequences.						P	
6. Proper polarity between pilot controls and flight controls.						P	
7. Capability of the CCMM in conjunction with the DCM to provide Navigation updates via precision ranging.						P	
8. Capability of DCM to satisfactorily select the optimum antenna as a function of attitude or mission phase.						P	
9. Capability of COMM to transmit and receive intelligible avionics data.						P	

Table 6-4. Avionics Subsystem Integration Laboratory Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
10. Capability of body rate sensors, in conjunction with the DCM and flight control system, to suppress body bending.						P	
11. Capability of TVC to maintain proper boost trajectory.						P	
12. Flight control system gains.						P	
13. Stability of control loops using the frequency response method.						P	
14. Adequacy of flight control loop data sampling rates for performing critical flight maneuvers.						P	
15. Ability of air data sensors in conjunction with the DCM to perform the required tasks.						P	
16. Proper flight control gain scheduling, switching, and acceptability of resulting transients.						P	
17. Capability of acquisition, control and test units (ACT) to facilitate communication between the subsystems and the DCM computer.						P	
18. Capability of the data management computer to provide for automatic sequencing, configuration control, IMU initialization computation, attitude determination, gimbal control of MPS, ignition control of OMS and ACPS, thrust control of ABES, aerodynamic surface control, GN&C display data computations and checkout, and fault isolation of GN&C system.						P	
19. Capability of reconfiguring the GN&C to the various modes via the FC panel.						P	
20. Capability to make navigation and docking sightings within the required limits of the telescope.						P	
21. Capability of switching over from automatic flight mode to manual take-over.						P	

Table 6-4. Avionics Subsystem Integration Laboratory Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
22. Capability of commanding abort.						P	
23. Compatibility of GN&C with instrumentation.						P	
24. Compatibility with SE.						P	
25. Compatibility with electromagnetic interference/susceptibility requirements.						P	
26. Management of FO/FS redundancy.						P	
27. Ability of GN&C, precision ranging, DCM, and the flight controls to effect automatic landing.						P	
28. Adequacy of cooling system to maintain GN&C subsystem within specified temperature limits.						P	
29. Flight control system deadbands.						P	
30. Adequacy of GN&C software						P	
31. Re-entry and boost guidance performance.						P	
32. Adequacy of the safety lock and priority logic to prevent inadvertent initiation of hazardous functions.						P	
AVIONICS/NONAVIONICS INTEGRATION REQUIREMENTS							
1. Ability of EPD&C subsystem to operate in redundant modes.						P	
2. Ability of EPD&C to deliver electrical power with specified characteristics to all loads from airborne, ground, and space station sources.						P	
3. Ability of EPD&C to meet all power delivery, switching and redundancy requirements while under control of DCM, COFI, and D&C.						P	

Table 6-4. Avionics Subsystem Integration Laboratory Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
4. Ability of EPD&C to deliver specified power to the avionics loads during switching of key loads.						P	
5. Compatibility of DCM COFI programs with each nonavionics subsystem.						P	
6. DCM computer and related software is capable of supporting:						P	
a. Vehicle in-process and acceptance checkout.							
b. Turnaround safing, maintenance, preflight checkout and launch.							
c. Rapid transfer of computer programming and mass memory data across the vehicle/ground system interface.							
7. Ability of DCM and software to integrate the D&C, GN&C, and hydraulic power subsystems for end-to-end operation of flight controls during mission and ground checkout modes.						P	

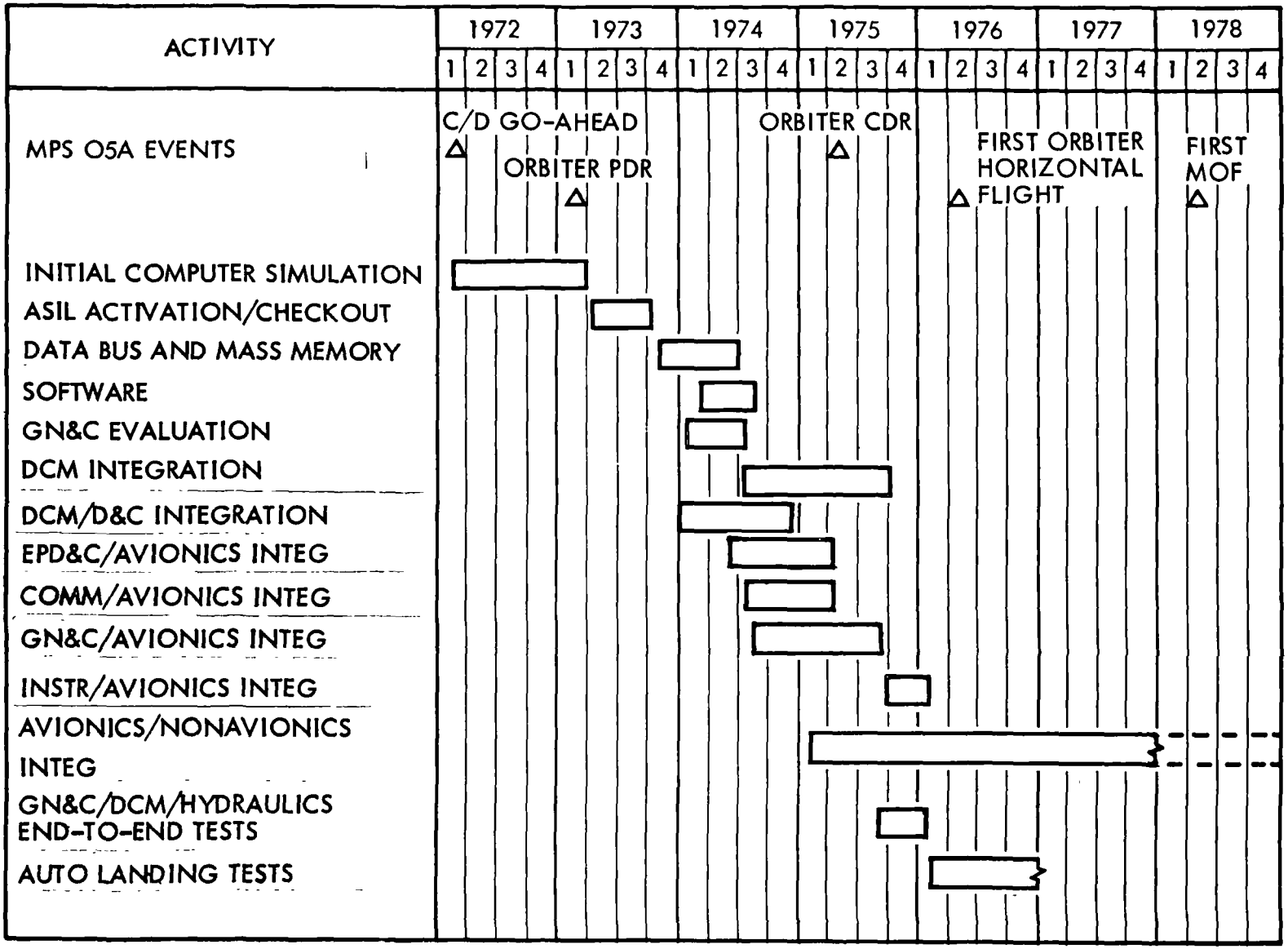


Figure 6-6. ASIL Test Schedule

Table 6-5. ASIL Test Hardware Requirements

Subsystem	Assembly	Quantity
DCM	CPU	6
	Main storage	150 percent
	Mass memory	150 percent
	ACT assemblies	90 percent
	Data bus harness	4
D&C	Multifunction controls	100 percent
	Multifunction displays	100 percent
	Dedicated D&C	20 percent
	Flight controls	100 percent
EPD&C	Transformer/rectifiers	3
	Inverters	6
	Ordnance controller	1
	Power distribution boxes	100 percent
	Assorted power controllers	75 percent
	Generator control unit	3
GN&C	IMU	3
	Rate sensors	100 percent
	Air data system	1
	Star tracker assembly	1
	Drive electronics	100 percent
	Pilot flight controls position transducers	100 percent
Instrumentation	DFI:	
	DFI data bus	20 percent
	Acquisition and signal conditioning unit	2
	DFI format controller	1
	Recorder	1
	Wideband conditioner	1
	Selected transducers	50 percent
	DFI displays and controls	1
	Select buffer	1

Table 6-5. ASIL Test Hardware Requirements (Cont)

Subsystem	Assembly	Quantity
Instrumentation (Cont)	OPERATIONAL:	
	Selected avionics transducers	50 percent
	Selected nonavionics transducers	5 percent
	Central timing equipment	1
COMM	S-band power amplifier	1
	Unified S-band equipment	1
	Flight log recorder	1
	Signal processor	4
	Precision ranging generator (PRG)	4
	Audio center	2
	Radar altimeter	2
	VHF recovery beacon	1
	ATC transponder	2
	ATC voice transceiver	2
	Orbiter/booster link and decoder	2
	Antenna selectors	5
	Passive target radar	1
	Crewmen audio headsets	100 percent
	VHF/FM transceiver	2
Structure (boilerplate)	Selected assemblies to simulate vehicle ground	as req'd
	Cabin electronics bay	75 percent
	Aft electronics bay	75 percent
	Crew compartment	90 percent
Hydraulic power	Hydraulics/controls lab described in Section 5.5 will be electrically connected to ASIL. Test hardware required for the lab is listed in Table 5-15.	See Table 5-15
APS	Propellant tanks gauging system	50 percent
Power Generation	APU generator	3
	Battery	2

Note: The hardware quantities identified are for subsystem level testing and do not include requirements for development or qualification of individual components and subassemblies.

Table 6-6. ASIL Test Support Requirements

Area	Requirement
Support equipment	Flight deck air conditioning Avionics cooling Simulated visual presentations for (1) landing, (2) rendezvous and docking, (3) celestial navigation Simulated electrical loads RF and telemetry analysis and stimuli capability Computer and software for nonavionics subsystems simulation, test control, and data reduction. Prime movers (3) for APU generators Table for IMU and rate sensors.
Facility	Air conditioning GN_2 supply and distribution 115-v single-phase 60-Hz power 440-v 3-phase 60-Hz power 120/208 3-phase 400-Hz power 28-vdc regulated power
Software	DCM test program for initially operating and checking the DCM prior to availability of the flight program. ASIL test program executed by the DCM computers for special integrated tests at the ASIL. ASIL subsystem models executed by a support computer to simulate nonavionics subsystems during integration tests. FTV acceptance test programs executed by DCM for self check, other subsystem check, and integrated test of flight vehicles, as part of acceptance test programs.

Table 6-6. ASIL Support Requirements (Cont)

Area	Requirement
Software (Cont)	DCM executive programs executed by DCM to satisfy internal requirements. DCM support modules executed by the DCM in support of other shuttle subsystems.

6.3 ECLSS/CREW CABIN TEST PROGRAM

6.3.1 Configuration

The test article will consist of a body structure containing ECLSS assemblies and selected portions of other subsystems. All ECLSS assemblies, except the space radiators, will be installed in the crew, passenger and airlock compartments, galley area, and avionics bay. Portions of other subsystems, such as the flight personnel provisions, EPD&C, D&C, DCM, instrumentation, and COMM, will be installed to the extent required to support combined subsystem test. Figure 6-7 shows vehicle subsystems involved in the ECLSS/crew cabin test program.

6.3.2 Operations

Functional interplay between subsystems to be combined in the test article is shown on Figure 6-8. The body structure will physically house the ECLSS and avionics. Ground power will be distributed to the various subsystems using elements of the EPD&C. Transducers of the instrumentation subsystem will be used to gather test data. The subsystem will be monitored and controlled by test personnel using those elements of the displays and controls and the DCM related to the ECLSS. Flight personnel provisions such as seats and sleeping restraints will be used by personnel during testing. The installed avionics, as well as simulated heat loads, will be mounted on the coldplate network for thermal loading of that assembly.

6.3.3 Requirements

Combined subsystem certification requirements to be satisfied using this test article are summarized in Table 6-7. Basically, the requirements deal with performance of the ECLSS while integrated with the body structure and certain other vehicle subsystems.

6.3.4 Approach and Rationale

As stated in the subsystem test description, most ECLSS assemblies will be designed, developed, and in some cases certified by subcontractors. Integration of these assemblies with the body structure will be done by the orbiter contractor using the test article.

Since nominal cabin working pressure is 14.7 psi, crew cabin/ECLSS laboratory tests will be performed at or near ambient pressures, thereby simplifying design of the test article. Although the cabin pressure range has a low of 10 psia, integrated testing at this low level will not be necessary. Analysis and Apollo experience combined with component and subassembly testing at the lower pressure level will be indicative of 10-psia ECLSS

performance. Heat transfer into and out of the cabin will be generated by heaters and cooling coils mounted on the exterior. Actual and simulated thermal loads will be imposted on the coldplate network. Generally, personnel will be used for metabolic loading of the ECLSS. For tests where use of personnel is not feasible, metabolic loading will be simulated by introduction of sensible and latent heat, CO_2, and by reduction of the partial pressure of the O_2 in the cabin air. Coolant loop heat will be rejected to an SE cooling unit, sublimator, or hydrogen heat exchanger, depending upon the mission mode being simulated.

The prime reason for choice of the ECLSS/crew cabin laboratory for combined subsystem tests is that schedules permit only a brief time for testing on the first flight vehicle. Since the ECLSS consists of a number of subcontractor developed assemblies which are installed in a body structure developed by the orbiter contractor, some facility is required to bring them together. The ECLSS/crew cabin was deemed a cost-effective approach to this need.

Testing in the ECLSS/crew cabin will be the first opportunity for all ECLSS assemblies to be operated together as a system. Such issues as ability to properly condition and distribute cabin air, temperature control of electronic equipment, ratio control of cabin gases, interface between major assemblies, effectiveness of the various control systems and interface with the DCM will be verified. Generally, verification will be accomplished by "flying" simulated missions in the test unit. The DCM and its data bus will be simulated by a support computer and special test software. The support computer will also be used for control of stimuli and data acquisition. The ECLSS will be certified for flight use during this phase of the test program.

A preliminary schedule is given in Figure 6-9.

6.3.5 Test Article Requirements

Test hardware requirements are summarized in Table 6-8.

6.3.6 Support Requirements

Support requirements are summarized in Table 6-9.

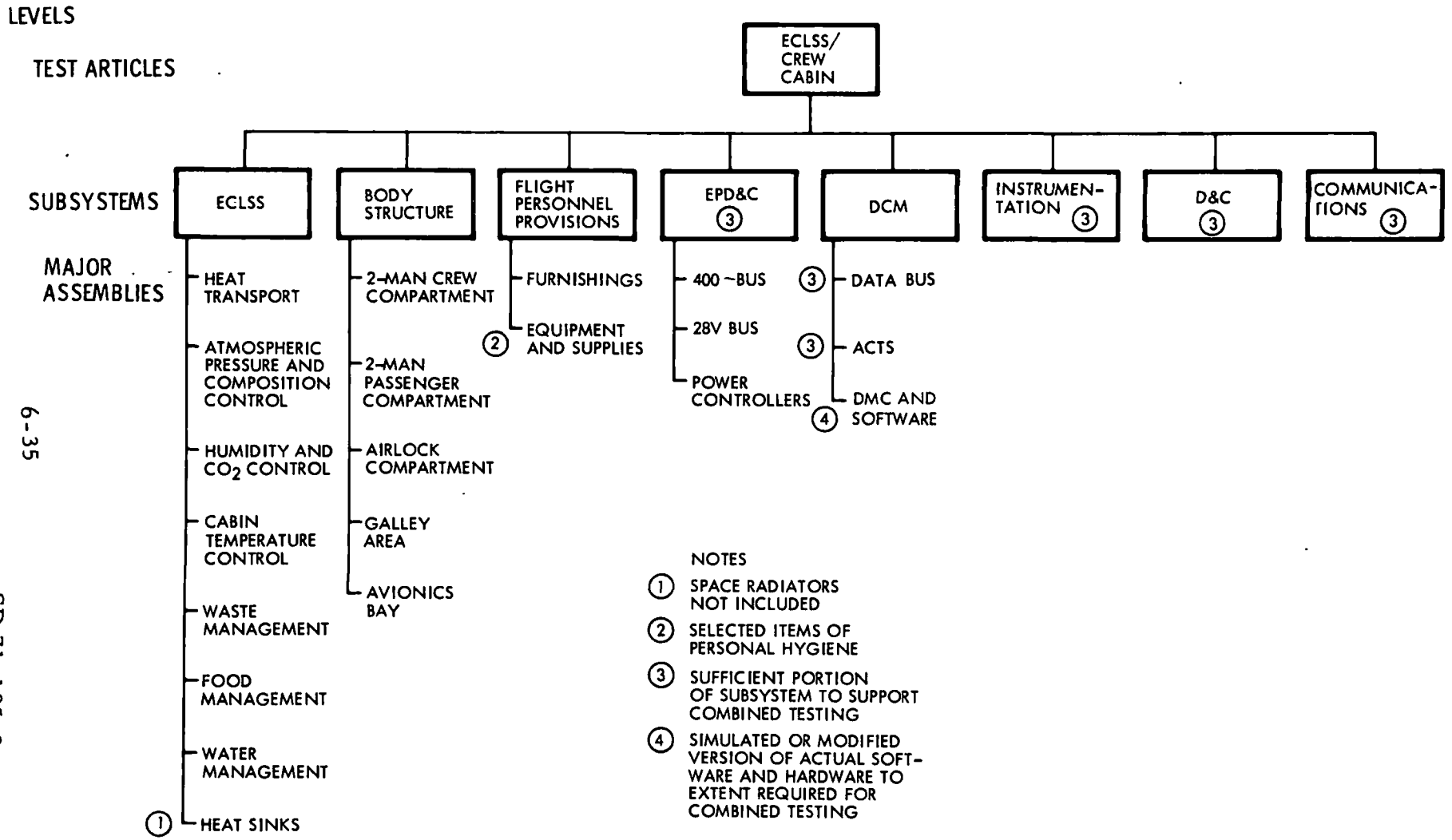


Figure 6-7. ECLSS/Crew Cabin Test Article Configuration Elements

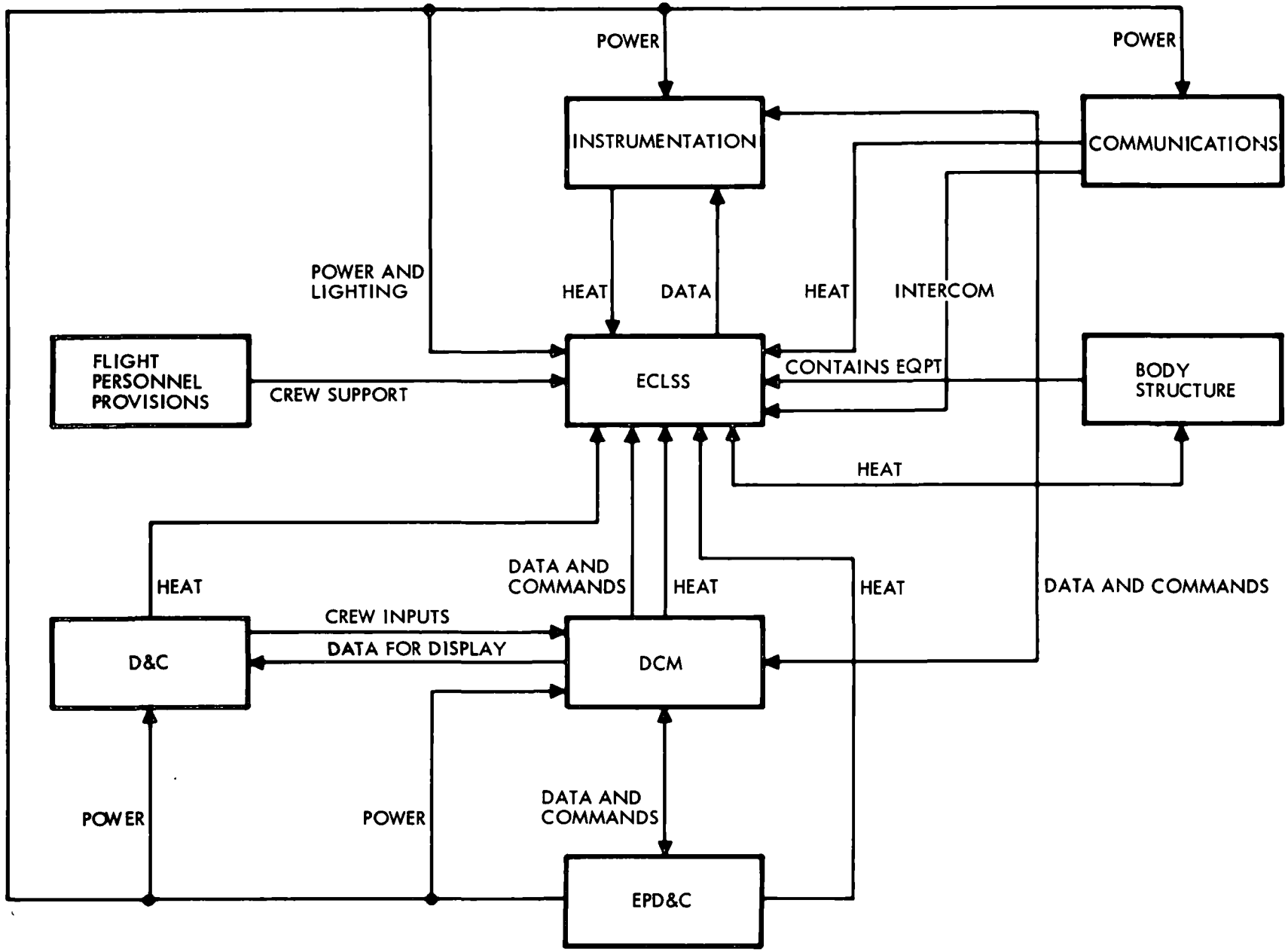


Figure 6-8. ECLSS/Crew Cabin Laboratory Schematic

Table 6-7. ECLSS Combined Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
1 Capability to distribute conditioned air without causing discomfort to crew members.						P	
2 Compatibility of coldplate network and other heat exchangers with crew cabin and other ECLSS assemblies.						P	
3 Capability of automatic and manual controls for the sublimators and the H_2 heat exchangers.						P	
4. Compatibility of water assemblies with crew cabin and other ECLSS assemblies.						P	
5. Adequacy of water removal, treatment and storage from humidity heat exchangers and from fuel cells.						P	
6. Adequacy of water supplied for operation of sublimators and for potable uses.						P	
7. Serviceability of water tanks, humidity control heat exchangers, and the sublimators.						P	
8. Compatibility of CO_2 and humidity control with other ECLSS assemblies and with the crew cabin.						P	
9. Adequacy of automatic and manual controls of the CO_2 and humidity control system.						P	
10. Capability of air cooling to provide desired humidity levels.						P	
11 Maintenance of cabin CO_2 levels within limits.						P	
12. Distribution of conditioned air without discomfort or condensation on any external surface.						P	
13. Compatibility of the cabin temperature assembly with other ECLSS assemblies and with the cabin.						P	
14. Automatic and manual control of the cabin temperature assembly.						P	

Table 6-7. ECLSS Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
15. Provision by cabin temperature assembly of specified amounts of heating and cooling for the cabin air.						P	
16. Compatibility of the pressurization assembly with cabin and with other ECLSS assemblies.						P	
17. Adequacy of normal and emergency cabin pressurization systems.						P	
18. Acceptance by systems of O_2 from the PRSD and N_2 from the N_2 storage vessel.						P	
19. Provision of sufficient gas for water tank pressurization and cyclic accumulator operation.						P	
20. Serviceability of the N_2 storage vessel.						P	
21. Compatibility of the waste management assembly with crew cabin and other ECLSS assemblies.						P	
22. Ability to dump liquid wastes.						P	
23. Usability of solid and liquid waste system while within confines of the crew cabin.						P	
24. Compatibility of the food management assembly with crew cabin and with other ECLSS assemblies.						P	
25. Ability to provide drinking water and to prepare, serve, and consume meals within confines of the crew cabin.						P	
26. Integrated performance of all ECLSS assemblies within the crew cabin.						P	
27. Overall ability of the ECLSS to respond to management direction of the data control and management subsystem.						P	
28. Functional performance of redundant subassemblies.						P	

Table 6-7. ECLSS Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	1 Analysis	2 Computer/Model	3 Component	4 Assembly	5 Subsystem	6 Comb. Subsystem	7 Flight Vehicle
29. Ability to service N_2 vessel, sublimators, water systems and humidity control heat exchangers.						P	
30. Ability of ECLSS to support ground and horizontal flight requirements.						P	
31. Maintenance of cabin noise level from ECLSS operation within allowable limits.						P	
32. Adequate automatic and manual control of the hydraulic and fuel cell heat exchangers.						P	
33. Adequate automatic and manual control of the 3 fluid intercooler.						P	
34. Ability of heat exchanger rates between the water and freon loops, via the intercooler, to stay within specified limits.						P	
35. Ability to provide ECLSS cooling, while on the ground, by circulation of ground coolant through the intercooler.						P	
36. Compatibility of the cold wall heat exchangers with the cabin and with other ECLSS assemblies.						P	
37. Functional performance of the cold wall heat exchangers and associated controls, in the cabin.						P	
38. Ability of crew to adequately monitor/control ECLSS using displays/controls in the cabin.						P	
39. Functional performance of water and freon pump assemblies while under load in crew cabin.						P	

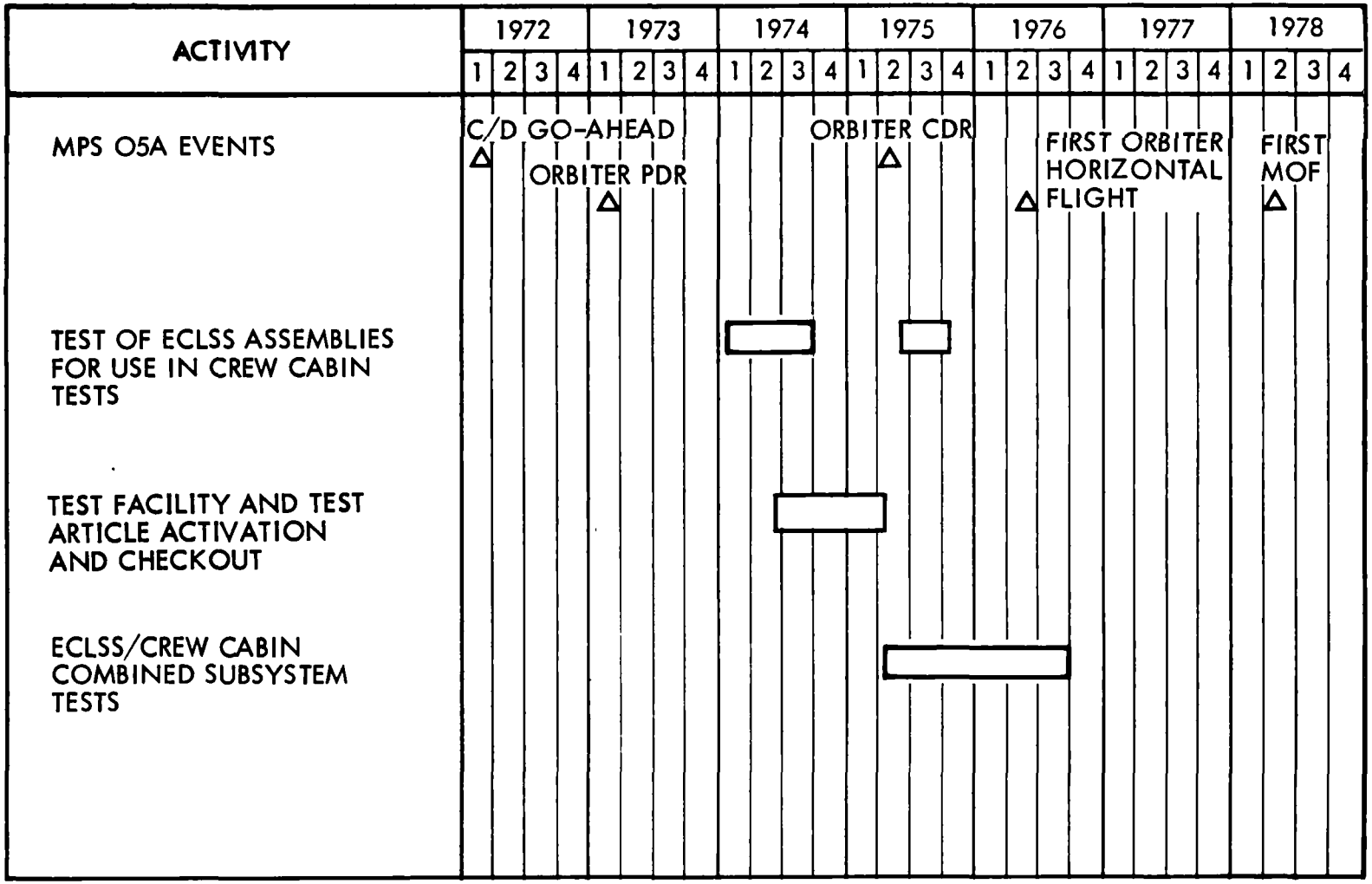


Figure 6-9. ECLSS/Crew Cabin Test Program Schedule

Table 6-8. ECLSS/Crew Cabin Test Program Test Article Requirements

Subsystem	Assembly	Quantity
ECLSS	Heat transport	100 percent
	Atmospheric pressure and composition control	100 percent
	Humidity and CO_2 control	100 percent
	Cabin temperature control	100 percent
	Waste management	100 percent
	Food management	100 percent
	Water management	100 percent
	Heat sinks	90 percent (less space radiators)
	Ferry kit heat sink	1
Body structure	2 man crew compartment	1
	2 man passenger compartment	1
	Airlock compartment	1
	Galley area	1
	Avionics bay (fwd bay only)	1
Flight personnel provisions	Furnishings	100 percent
	Equipment and supplies	20 percent
EPD&C	400-Hz bus	10 percent
	28 v bus	10 percent
	Power controllers	10 percent
DCM	Data bus harness	10 percent
	ACT assemblies	5 percent
Instrumentation	Transducers and signal conditioners	10 percent
D&C	ECLSS displays/controls	100 percent
COMM	Voice intercom	75 percent

Table 6-9. ECLSS/Crew Cabin Test Support Requirements

Area	Requirement
Facility	Electric power: 60-cycle 3-phase - 120 v, 440 v; 400-cycle 3-phase - 120 v; 28 vdc Water: Firex, demineralized, potable Air conditioning/heating/ventilation GO_2 storage/transfer GN_2 storage/transfer He storage/transfer Freon storage/transfer Hydrogen storage/transfer Weatherproof test area
Support equipment	Control/simulation/data acquisition computing capability Crew cabin, passenger cabin, air lock air conditioning Ground cooling (I/F with 3 fluid intercooler) Vacuum pump (3 requirements: (1) lower cabin pressure approximately 1 psi; (2) operate sublimator; (3) evacuate fluid lines for servicing) Water loop servicing Freon loop servicing Test gas regulation/distribution Heating/cooling units for cabin outside walls

Table 6-9. ECLSS/Crew Cabin Test Support Requirements (Cont)

Area	Requirement
Support equipment (Cont)	CO_2 supply Metabolic load simulator (outputs CO_2, moisture, heat) Noise measuring apparatus Air flow measuring equipment Leak detector Test control console
Software programs	Control of test sequence Control of simulated loads Data acquisition Simulation of DCM Test reporting Provide CRT display of test data Data analysis

6.4 AUXILIARY PROPULSION SUBSYSTEM (APS) STATIC FIRING PROGRAM

6.4.1 Configuration

The orbiter APS static firing test article will consist of the following vehicle assemblies: three orbit maneuvering engines, three gas generator/heat exchanger/turbo-pump packages, one bank of attitude-control thrusters, one APU and exhaust, cryogenic tankage, propellant feed ducts, pressurization assembly, and partial avionics and thrust vector control subsystems to provide instrumentation, control, checkout, and engine gimbal. Figure 6-10 represents the APS static firing test article subsystems requirements.

6.4.2 Operations

The orbiter APS test article operation is depicted in block flow diagram in Figure 6-11.

6.4.3 Requirements

The orbiter APS static firing program requirements are listed by subsystem in Table 6-10.

6.4.4 Approach and Rationale

Integration of the orbit maneuvering, attitude control, and APU assemblies has resulted in many significant integrated test requirements that are best resolved by a static firing program. Development of a gas generator heat exchanger/turbo-pump package to support the orbit maneuvering engines, attitude-control thrusters, and the APU's will require significant testing. Since mission-to-mission variations will result in varying attitude-control propellant consumption rates, no firm time-line can be generated for power package operation. Consequently, the turbo-pumps must be continuously chilled down. Development of the chill-down system for operation in a zero-g environment will also require a significant test program. As the components and assemblies reach desired stages of development they will be bread-boarded into subsystems and tested to verify their compatibility. Following this, these subsystems will be installed into the APS test article. This major test article will be a separate entity from the flight vehicle but will closely simulate the actual geometry and relationship of elements within the vehicle. Elements of other major vehicle subsystems that interface with the APS; such as avionics, instrumentation, SE, displays and controls, etc., will also be utilized during the integrated testing to further evaluate their respective interfaces.

During most phases of testing (vehicle ground and flight testing being the major exception), it will be necessary to provide special test hardware that will allow operation of the OMS at a simulated altitude. Exhaust ejection systems will be utilized for this purpose.

Following completion of testing on the APS test article, the hardware may be incorporated into the production inventory if reinspection results, time accumulation, configuration, test history, etc., prove acceptable.

Figure 6-12 represents the APS development schedule and includes the static firing program.

6.4.5 Test Article Requirements

Table 6-11 summarizes hardware requirements for the test program.

6.4.6 Support Requirements

The major support requirements for the APS static firing program are listed in Table 6-12.

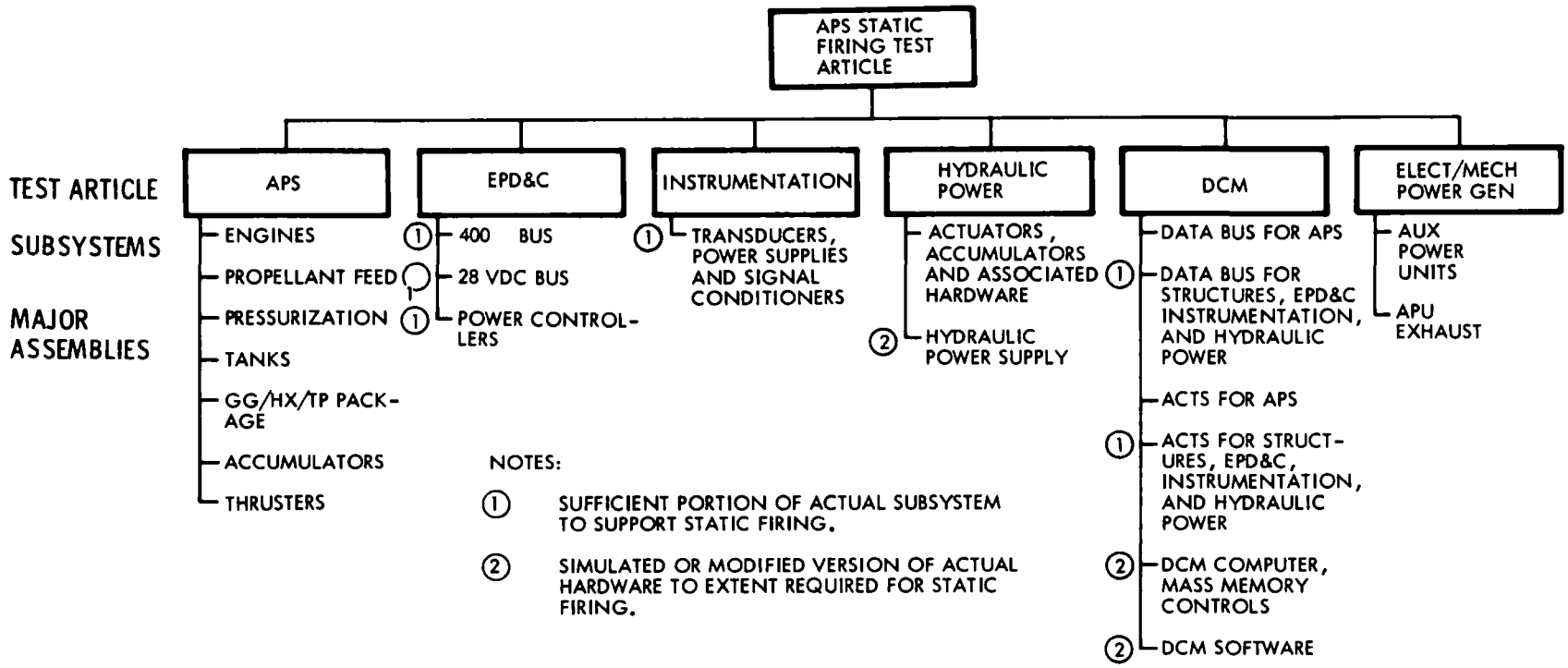


Figure 6-10. Test Article Configuration Elements

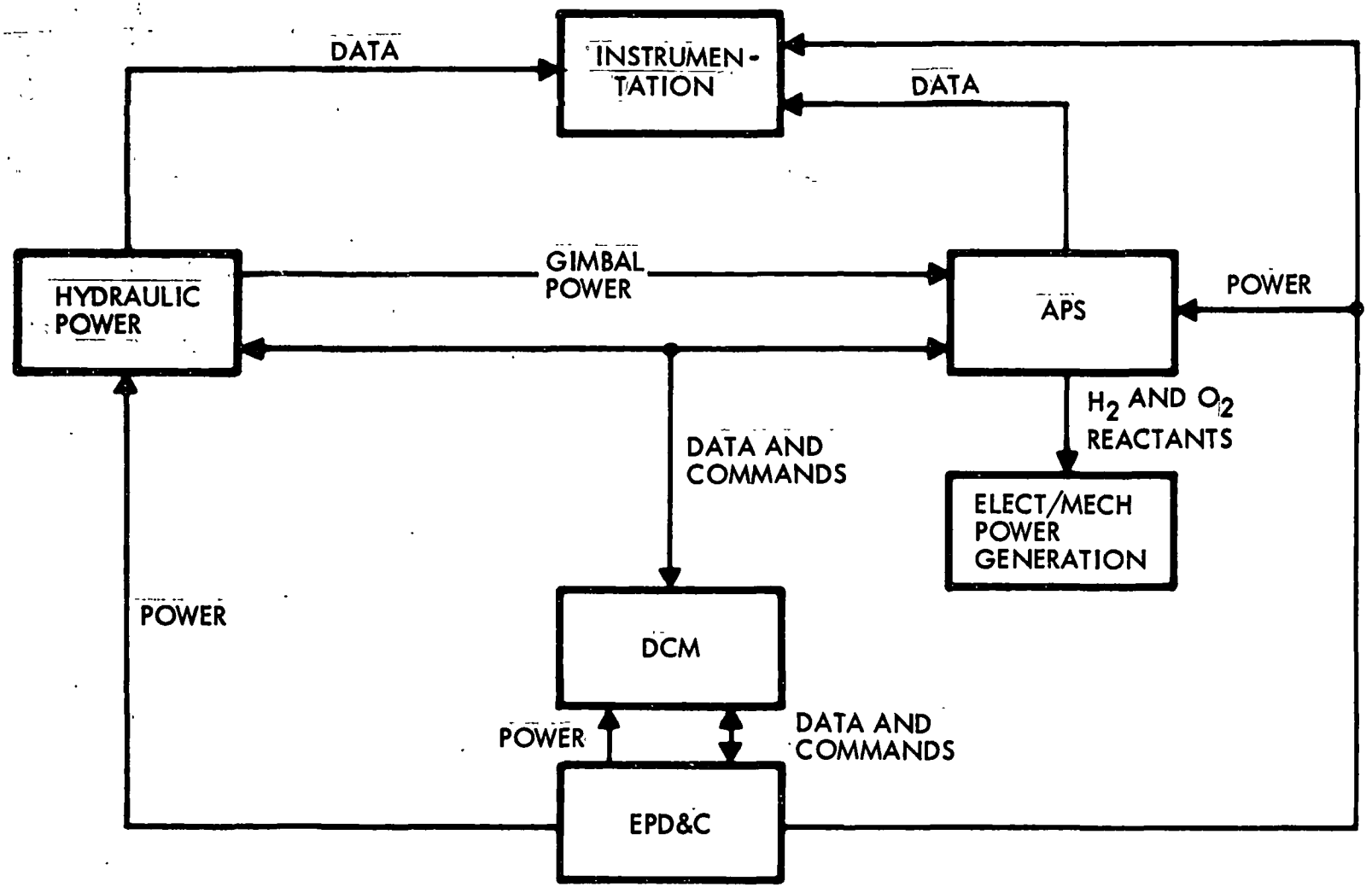


Figure 6-11. APS Static Firing Test Article Schematic

Table 6-10. APS Combined Subsystem Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
SUBSYSTEM REQUIREMENTS							
1 Capability of subsystem to provide the required orbit maneuvering attitude control impulse						P	
2 Ability to activate subsystem prior to deorbit						P	
3. Ability of subsystem to operate under all ground and flight conditions without structural and/or feed system coupling						P	S
4. Capability of subsystem to withstand vibration and acoustic effects from MPS operation	S					P	S
5 Capability of subsystem to provide the required attitude control and orbit maneuvering response						P	
6 Capability of subsystem to operate after long periods of on-orbit inactivity	S					P	S
7 Ability to maintain thermal control of subsystem elements during on-orbit dormancy	S					S	P
8 Accessibility of in-tank components for repair or replacement						P	
9 Capability of subsystem to provide the required thrust in pitch, yaw, roll						P	S
PROPELLANT PRESSURIZATION AND VENT ASSEMBLY (NORMAL AND THERMAL)							
1 Ability to maintain tank pressure during boost						P	S
2 Ability to service tanks with ground vehicle/GSE vent system in the required time period.						P	S
3 Capability to pressurize LO_2 and LH_2 tanks with ground pressurization						P	S
PROPELLANT STORAGE AND FEED ASSEMBLY							
1 Ability to provide propellant to the pump inlets at the required conditions (temperature and pressure) for ground and flight operations						P	

Table 6-10. APS Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
2. Compatibility of propellant fill and drain servicing/distribution line.						P	
3. Ability to drain tanks in horizontal attitude.						P	
4. Capability to monitor and evacuate vacuum-jacketed feed lines						P	
5. Capability of retention screens to withstand propellant loading loads.						P	S
PROPELLANT CONDITIONING AND DISTRIBUTION ASSEMBLY							
1. Capability to repressurize LO_2 and LH_2 tanks for deorbit operations.						P	
2. Ability of orbit maneuvering engines to provide GH_2 for attitude-control motors, tank pressurization, and APU's						P	
3. Capability of LO_2 turbopump heat exchanger auxiliary coils to provide LO_2 for attitude-control motors, tank pressurization, and APU's.						P	
4. Capability of assembly to provide inlet pressure at specified conditions and at specified response to the attitude-control thrusters and to the APU's.						P	
5. Capability of accumulators to provide the requirement impulse to the attitude-control thrusters.						P	
6. Capability of H_2 and O_2 gas generator and heat exchanger assembly to provide sufficient conditioned propellants for attitude-control thrusters, tank pressurization, turbopump, gas generator, APU and ECLSS operations.						P	
7. Ability of O_2 and H_2 accumulator vent and relieve assembly to maintain the accumulator pressure below the maximum allowable.						P	
PROPELLANT GAUGING ASSEMBLY							
Ability to determine propellant load within required limits.						P	

Table 6-10. APS Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
HOT GAS VENT ASSEMBLY (PROPULSIVE AND NONPROPULSIVE)							
Ability of vent to maintain proper back pressure on pump turbines, heat exchangers, etc.						P	
ATTITUDE CONTROL THRUSTER ASSEMBLIES							
1. Ability to leak check engine/vehicle interfaces.						P	
2. Capability to conduct engine functional sequence checks.						P	
3. Ability to change attitude control thrusters in horizontal or vertical attitude.						P	
ORBIT MANEUVERING THRUST CHAMBER ASSEMBLIES							
1. Ability to leak check engine/vehicle interfaces.						P	
2. Capability to conduct engine functional sequence check.						P	
APS/GSE							
1. Compatibility of subsystem/vehicle/GSE interfaces.						P	
2. Ability to inert engines, tanks, lines, etc.						P	
3. Capability to precondition LH_2 sections prior to propellant loading.						P	
DATA AND CONTROLS MANAGEMENT							
1. Ability of DCM to perform COFI.						P	
2. Functional interface between DCM and auxiliary propulsion subsystem.						P	
3. Compatibility of TVC with engine-start transients.						P	

Table 6-10. APS Combined Subsystem Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
4. Compatibility of TVC with the maximum loads encountered.						P	
5. TVC Phase lag and acceleration rates.						P	
6. Performance requirements under standby conditions.						P	
STRUCTURES							
1. Structural modal characteristics under various engine operating conditions.						P	
2. Structural stability characteristics.						P	
3. Structural compliance.						P	
EPD&C							
Compatibility of power controllers with their APS interfaces.						P	
INSTRUMENTATION (DFI AND OPERATIONAL)							
1. Compatibility of transducers and signal conditioners with their APS and structures interfaces.						P	
2. Compatibility of transducers and signal conditioners with their ACT interfaces.						P	
HYDRAULIC POWER							
1. Ability of hydraulic power subsystem to provide sufficient output to support mission requirements.						P	
2. Compatibility of hydraulic power actuators and OMS engine under operating environment.						P	
ELECTRICAL/MECHANICAL POWER GENERATION							
Ability to provide specified output while being fed propellants from the APS accumulators.						P	

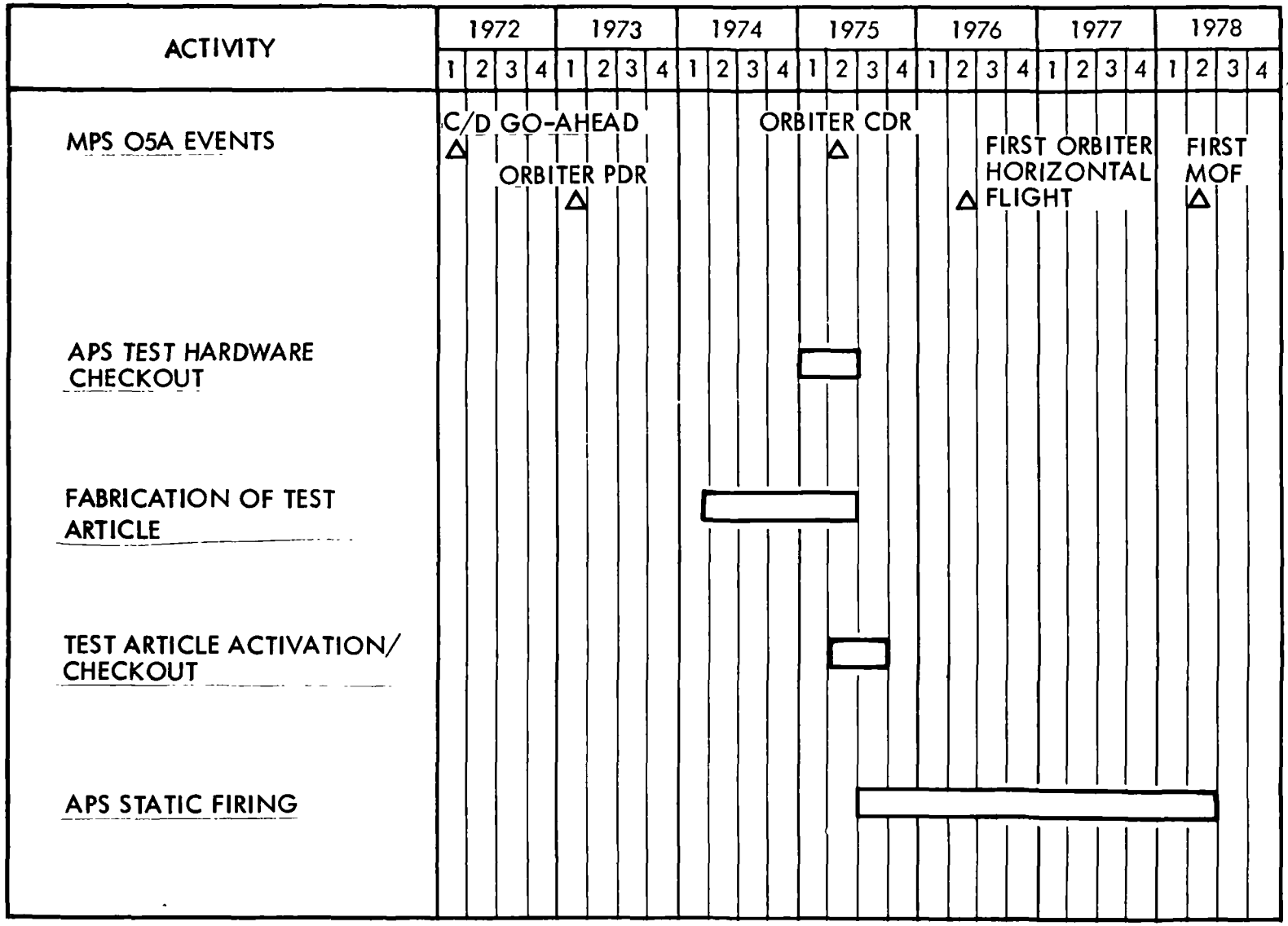


Figure 6-12. APS Static Firing Test Schedule

Table 6-11. APS Static Firing Test Hardware Requirements

Subsystem	Assembly	Quantity
APS	Thrusters	15
	Engines	3
	Tank set	1 set
	Propellant feed/distribution/servicing	100 percent
	Pressurization	100 percent
	Gas generator/heat exchanger/ turbo pump	100 percent
EPD&C	400 - Hz bus	
	28 volts dc bus	
	Power controllers	
Instrumentation	Transducers, power supplies and signal conditioners, data recording	20 percent
Hydraulic power	OMS actuation	100 percent
	Hydraulic power generation assembly	1
Power generation	APU APU exhaust	1 100 percent
DCM	Data bus harness	30 percent
	ACT assemblies	
	CPU*	1
	Main storage*	40 percent
	Mass memory*	40 percent

*Ground support computer also being considered, in lieu of airborne items listed.

Table 6-12. APS Static Firing Test Support Requirements

Area	Requirement
Facility	Flame deflector Water: firex, flame deflector cooling, potable LH_2 storage/transfer LO_2 storage/transfer GN_2 storage/transfer He storage/transfer H_2 disposal Test control room Electrical power: 60-Hz, 3-phase, 120 volts and 440 volts; 400-Hz, 3-phase, 120 volts; 28 volts d.c.
Support equipment	Static firing support structure Hydraulic servicing unit Hydraulic power unit Test gas regulation/distribution system Control/simulation/data acquisition computing capability Electrical power distribution unit Miscellaneous engine support/servicing equipment Hazardous gas detection
Software	Control of test sequence Simulation of DCM and GN&C

Table 6-12. APS Static Firing Test Support Requirements (Cont)

Area	Requirement
Software (Cont)	Data acquisition Test reporting Provide CRT displays of test data Data analysis

6.5 WIND TUNNEL TEST PROGRAM

6.5.1 Configuration

The wind tunnel test program will use appropriately sized models of the orbiter and booster for individual and mated testing to satisfy the investigative requirements. Since the size and configuration depend upon the flight regime to be explored, and the facility utilized, individual models will not be described.

6.5.2 Requirements

There are no CEI specification requirements for wind tunnel testing. However, because wind tunnel test data can be extrapolated to full-scale conditions with satisfactory correlation, the requirements for subscale testing are indirectly the same that define the aerodynamic, dynamic, and thermodynamic performance of the orbiter vehicle.

Table 6-13 presents the general requirements for wind tunnel testing. Detailed test requirements are defined in NR Memorandum SSP/FT/71-130, Proposed SSV Phase C/D Wind Tunnel Test Program. This memorandum delineates the aerodynamic, heat transfer, and structural dynamic test programs required for the orbiter, booster, and launch configuration. Proposed test schedules are included together with estimated facility utilization requirements. In addition, detailed test planning information is provided which specifies test objectives and priority, range of test variables, model requirements, and facility occupancy hours.

6.5.3 Approach and Rationale

Wind tunnel testing will be conducted to support design, development, verification, and refinement of the orbiter, booster, and mated vehicles. General objectives of Phase C/D wind tunnel program are to obtain test data for (1) analysis and development of design criteria, (2) refinement and evaluation of configuration changes, and (3) substantiation of analytically predicted performance and design environment. The main test categories are aerodynamics, heat transfer, and structural dynamics. Discrete test objectives have been assigned under each category as described in Table 6-14 and a summary Phase C/D wind tunnel test schedule is diagrammed in Figure 6-13.

The Phase C/D wind tunnel test program has been planned as a continuation of the testing accomplished during Phase B and planned up to Phase C. Figure 6-14 is a summary of Phase B wind tunnel and related test programs. Phase B models will be used at Phase C go-ahead in test

categories where early data are required (refined heating and aerodynamic stability and control). Phase C models will be employed as soon as they are available.

The following assumptions were made in designing this Phase C/D wind tunnel test program.

1. Maximum use will be made of NASA-controlled facilities.

2. Limited wind tunnel testing will be continued during the interim period beyond the completion of Phase B and up to the start of Phase C.

3. The model configurations in the interim period may not match the Phase C contractual design requirements exactly, but will be close enough to provide useful data for early design efforts in critical long-lead-time areas. These areas include establishment of flight control surface sizes and continuing tests to update heating rates and maximum temperature profiles for configuration refinements beyond Phase B designs.

4. A single orbiter and booster configuration will be developed, and a complete set of wind tunnel models will be required to provide detail design data before preliminary design review (PDR).

5. The extent of booster and launch vehicle tests is independent of the orbiter mission.

6. Phase C design studies, coupled with the completion of booster and orbiter PDR's, will introduce enough changes that a new set of models is required. They will then be used in development testing to support final design of the flight hardware.

7. Modifications to models will be made as required in both Phase C and Phase D to support testing of vehicle design changes.

8. Models for special tests (spin characteristics and recovery, and ditching) will be designed after the completion of Phase C, and tested before CDR.

9. Additional models will not be required for verification tests, which would continue beyond critical design review (CDR) and through the horizontal flight test programs for the orbiter and the booster.

10. All wind tunnel testing will have been completed before the first manned orbital flight.

The Phase C/D wind tunnel test program rationale was to expand upon the work conducted prior to and throughout Phase B and to use the largest possible models and the maximum performance capabilities of existing wind tunnel facilities throughout Phase C/D.

An attempt has been made to obtain the highest possible assurance of flightworthiness with the lowest possible expenditure of test hours and test dollars. The wind tunnel test plan has been integrated with the flight test program. Subsonic flight characteristics predicted by wind tunnel test will be verified through the orbiter horizontal flight test program. Wind tunnel data and analysis will be the basis for qualification for vertical flight. The problem of verifying the behavior of the orbiter in the transonic regime is under continuing study. The present flight test baseline provides for verification of transonic flight characteristics during reentry from manned vertical flights.

As depicted in Figure 6-13, wind tunnel test planning for Phase C/D is subdivided according to flight phases (launch, entry, transition, cruise, and landing). It is further subdivided according to the technology areas of aerodynamics, heat transfer, structural dynamics, and special tests. These areas are discussed further in the following paragraphs.

Aerodynamic Tests

Within the limitations of existing facilities, aerodynamic wind tunnel tests will be used to determine and to verify space shuttle air vehicle performance, stability and control, air loads and pressure distribution, and the effectiveness of aerodynamic control surfaces. Various ranges of angles of attack and angles of yaw will be investigated. In addition, rotary derivatives and base pressure-base flow characteristics will be defined.

Additional tests required on the orbiter include the effects of drag flaps or speed brakes, the landing gear, and the air-breathing engine system (ABES) pods. ABES inlet performance will be measured. The emergency escape (ejection seat) systems will be modeled to determine trajectory boundaries and ejection limitations. Spin and spin recovery behavior will be studied by static force tests at high angles of attack and by small-scale models in spin tunnel facilities. Investigations of control surface forces and hinge moments will be supplemented with tests of the effects of the attitude control propulsion system (ACPS) to optimize the design of the control system. Tests will be run on models which simulate structural deformation due to aeroelastic effects in the high-load flight range.

Additional tests required on the launch configuration are determination of interference forces, moments, loads, and pressure distributions on each vehicle as a result of the presence of the other. Aerodynamic data must also be measured during simulated launch and separation phases for nominal and abort conditions.

Three engine systems impact aerodynamic performance of the space shuttle vehicles: (1) the main engine propulsion system (MPS), (2) the ABES, and (3) the ACPS for the orbiter and the booster as individual vehicles. Elements of engine system investigations are contained in both aerodynamic and heat transfer wind tunnel test studies.

Wind tunnel tests will determine the effects of the MPS exhaust on the booster and launch vehicle base drags to provide basic data for both nominal operations and for subsequent abort studies. Effects on orbiter base drag will also be determined for the abort studies.

The effect of the ABES exhaust on base drag will also be determined, together with the overall effects of ABES engine operation on other aerodynamic parameters. Heating and acoustic data will be obtained.

Orbiter and booster ACPS control and heating effects will be measured to establish local flow field and shock interaction phenomena.

Heat Transfer Tests

Aerothermodynamic environments that determine the thermal structural design requirements are developed from the extrapolation of theoretical prediction techniques and wind tunnel test results. Initial wind tunnel tests will employ paint models to determine constant temperature contours. Streamlines and flow fields will be determined with pressure models. Finally, larger-scale thermocouple models will be used to verify earlier results and to obtain more detailed temperature data and heating rate information.

Structural Dynamics Tests

Wind tunnel testing will be accomplished on large-scale models of the aerodynamic surfaces for the space shuttle vehicles and on smaller-scale complete vehicle models to determine structural dynamic responses. Wind tunnel tests will provide preliminary design, advanced design, and final verification of structural dynamic data as the air vehicles designs progress. For flutter margin assurances, models will be constructed with scaled nominal stiffness and with reduced stiffness for the flight regime determined to be most critical. The orbiter and booster dynamic models used to investigate flutter and buffet will be mated for a study of launch vehicle structural

dynamics in other than the liftoff flight region. The liftoff region requires flexible models of the mated configuration. Responses to simulated ground winds will be measured by utilizing a scaled stiffness mated model on a flexible base.

Structural-dynamics wind tunnel tests will provide air vehicle design data both directly and by providing assurance for the analytical methods used to calculate dynamic responses and flutter margins.

Special Test Requirements

Special tests have been identified that are required to verify and/or expand wind tunnel test results. These tests require models to verify spin behavior and spin recovery characteristics and to investigate water and land ditching dynamics.

Spin characteristics are initially derived through analysis that uses configuration properties and wind tunnel force and pressure distribution data from high-angle-of-attack tests. Next a model is constructed for free-flight testing in a facility such as the Langley spin tunnel. If additional testing is required, a spin model can be launched from a helicopter and recovered by parachute. Spin recovery procedures are correspondingly evaluated, improved, and verified throughout the spin test program.

6.5.4 Support Requirements

Table 6-15 lists the wind tunnels considered in the development of this test program. Other facilities may be added or substituted for those listed because of scheduling problems or other considerations.

Table 6-13. Wind Tunnel Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Models	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
1. Appropriate speed, angle or attack, and Reynolds number simulation of mated vehicle launch trajectories.		P					
2. Appropriate speed, angle of attack, and Reynolds number simulation of orbiter normal and abort separation conditions.		P					
3. Appropriate speed, angle of attack, and Reynolds number simulation of orbiter entry.		P					
4. Appropriate speed, angle of attack, and Reynolds number simulation of orbiter transition and cruise conditions.		P					
5. Appropriate speed, angle of attack, and Reynolds number simulation of orbiter landing conditions.		P					
6. Appropriate temperature and angle-of-attack simulation of mated-vehicle launch trajectories.		P					
7. Appropriate temperature and angle-of-attack simulation of orbiter entry conditions.		P					
8. Establishment and verification of orbiter aerodynamic configuration.		P					
9. Establishment and verification of orbiter structural and control loads.		P					
10. Establishment and verification of orbiter pressure distributions.		P					
11. Establishment and verification of static and dynamic stability and control.		P					
12. Establishment and verification of separation characteristics.		P					
13. Establishment and verification of power effects.		P					
14. Establishment and verification of aeroelastic loads and flutter characteristics.		P					

Table 6-13. Wind Tunnel Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Models	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
15. Establishment and verification of orbiter aerothermodynamic characteristics.		P					
16. Establishment and verification mated aerothermodynamic characteristics.		P					

Table 6-14. Wind Tunnel Test Categories

Area	Category
Aerodynamics	Stability and control forces and moments
	Hinge moments
	ABES base drag and inlet performance
	Pressure distribution for loads
	Spin force tests
	Escape system
	Dynamic stability
Heat transfer	Heat transfer distribution; phase paint, thermal coating, calorimeter, film gauge
	Base heating, plume heating
Structural dynamics	Flutter
	Flexible ground wind model loads
	Pressure distribution for aero noise
Special tests	Controlled water and land ditching
	Spin tests, free flight

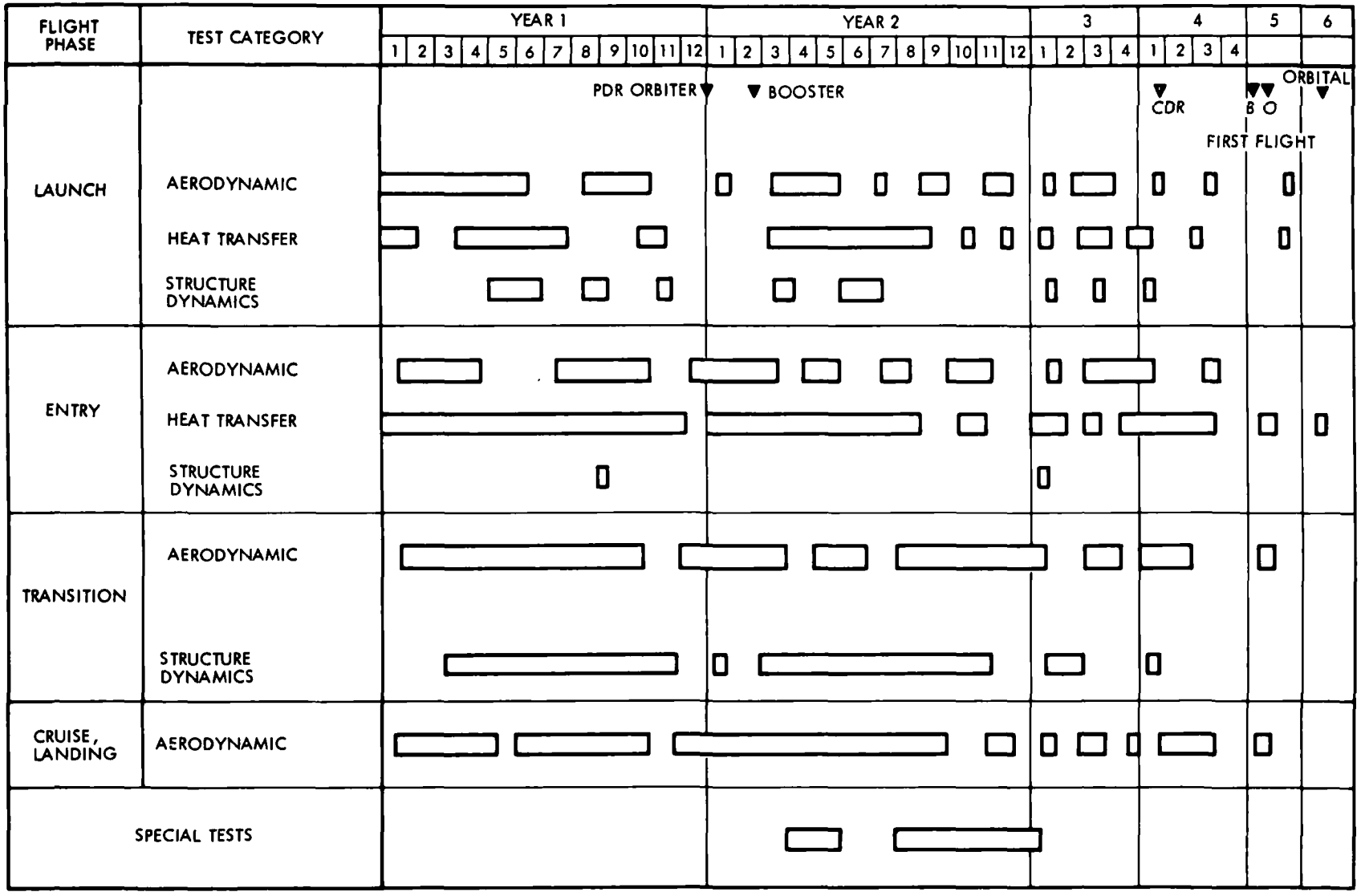


Figure 6-13. Summary SSV Phase C/D Wind Tunnel Test Schedule

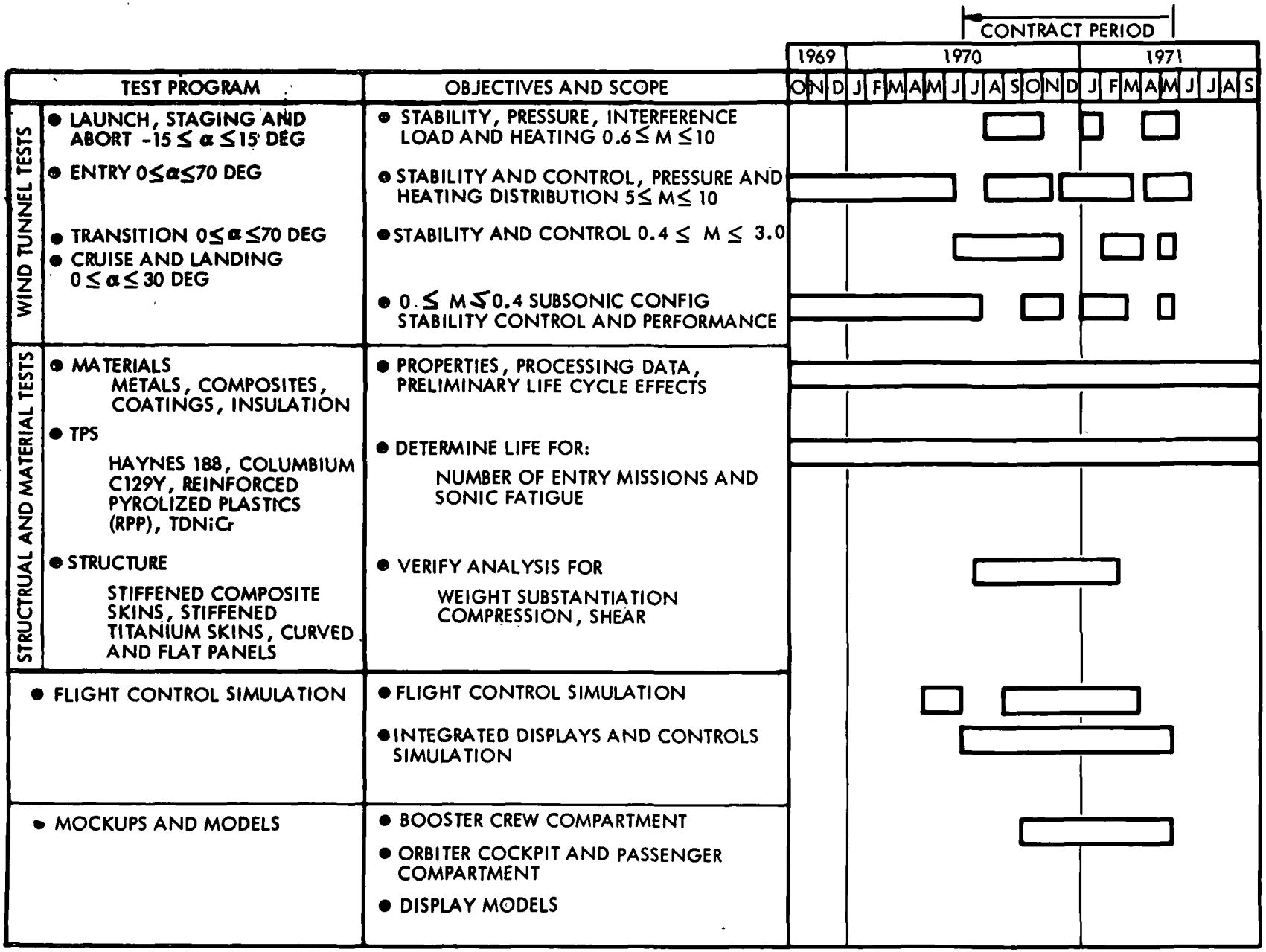


Figure 6-14. Summary of Phase B Wind Tunnel and Related Test Programs Schedule

Table 6-15. Candidates for Phase C/D Wind Tunnel Facility Use

NASA Facilities		
Ames Research Center	ARC 6 x 6 ft	M = 0.6 → 2.0
	ARC 3.5 ft	M = 5.5, 7.4, 10.4
	ARC 12 ft pressure	M = 0. → 0.96
	ARC Unitary	M = 0.7 → 3.5
Langley Research Center	LRC LTPT	M = 0 → 0.4
	LRC 8 ft TPT	M = 0.2 → 1.3
	LRC Unitary	M = 1.5 → 4.5
	LRC 16-ft TDT	M = 0.1 → 1.2
	LRC 18-in. Var density	M = 8.0
	LRC 31-in. CFHT	M = 10.0
	LRC 20-in. spin	Low Speed
	LRC 9 x 6 ft thermal structure	M = 2 → 3.5
Marshall Space Flight Center	MSFC 14-in. Impulse base flow facility (IBFF) (vacuum chamber)	M = 0.6 → 5.0
Air Force Facilities		
Arnold Engineering Development Center	AEDC VKF 40-in. A	M = 1.5 → 6
	AEDC VKF 50-in. B	M = 6 → 8
	AEDC VKF 50-in. C	M = 10 → 12
	AEDC VKF 54-in. - 108-in.	M = 11 → 23
	AEDC PWT 16-ft	M = 0.5 → 4.7
	AEDC RTF 12.5-ft test cell	M = 0 → 3.0
Contractor Facilities		
Cornell Aerophysics Laboratory	Cal 96-in. HST	M = 7 → 17
General Dynamics Corp/ Convair Div	GD 4 by 4 ft	M = 0.6 → 5.0
	GD LS 8 by 12 ft	M = 0 → 0.3
	GD test stand	
North American Rockwell Corp.	NR TWT 7 by 7 ft	M = 0.2 → 3.5
	NR NAAL 7.75 x 11 ft	M = 0 → 0.26
(NASA Flight Test Center, Edwards, California, for halicopter drop tests) (Apollo Drop Test Facility, NR Downey, for ditching tests)		

6.6 INTEGRATED THERMAL CONTROL SUBSYSTEM

The function of the thermal control subsystem (TCS) is to maintain vehicle subsystems within their allowable temperature ranges during all mission phases. As such, the TCS involves all subsystems. The TCS is aided by the thermal protection subsystem, which forms the external surface of the vehicle and limits the temperature range of the primary structure during boost and entry, and the ECLS subsystem, which provides environment control for the crew and passengers and a majority of the electronic packages. The overall scope of the TCS is presented in Figure 6-15.

The overall TCS test program is summarized as follows:

1. Test Logic. Logic for TCS development is shown in Figure 6-16.

2. Test Article. Test articles required for TCS testing are listed in Table 6-16.

3. Schedule. A schedule showing TCS testing is given in Figure 6-17.

Because of the criticality of this test program, studies are continuing to ensure that the most practical and cost-effective approach will be taken.

6.6.1 Requirements and Configuration

Purge Gas Supply and Distribution

Requirements.

1. Adequate purge gas pressure and supply.

2. Sufficient inlet (to vehicle) gas temperature and humidity control.

3. Proper distribution of the purge gas to the various vehicle compartments.

4. Adequate gas flow rates.

Test Configuration. This setup will consist of a GN_2 supply with temperature and humidity control equipment, purge gas flow equipment, and a simulated space shuttle test article with the appropriate ducting and vents. Major internal components and equipment will be simulated to achieve the required volumes and flow areas.

Compartment Venting

Requirements.

1. Verification of compartment venting design.

2. Determination of internal pressure lag.

3. Adequacy of insulation installations.

4. Verification of venting analytical models.

Test Configuration. It is tentatively planned that a representative vehicle section will be used for this test (section of mid-body, including simulated ABES engine). Intercompartment areas will be sealed, and vent ports - representative of flight hardware - will be used. The entire section will be placed in a vacuum chamber with large pumping capacity, and the external compartment pressure will be decreased to simulate boost conditions, and later increased to simulate entry conditions.

Vehicle Purge

Requirements.

1. Proper temperature control of compartments.

2. Adequate flow distribution.

3. Detection and resolution of localized hot or cold spots.

4. Acquiring of adequate heat transfer data.

5. Determination of required purge gas inlet temperatures and flow rates.

6. Verification of purge system ducting.

7. Determination of required pressures for proper purging.

8. Verification of gas exit vents.

9. Verification of propulsion and power generation purge systems.

10. Testing of insulation performance under simulated pad-hold conditions.

11. Verification of thermal models used for pad-hold temperature predictions.

12. Determination of frost buildup and moisture accumulation effects.

13. Verification of flow models used to determine purge gas requirements.

Test Configurations. The MPS cluster firing test article (Section 6.1) will be used for this test, which includes the main LH_2 tank, the main LO_2 tanks, the vehicle structure, feed lines, and engines. In addition, the purge gas system, with appropriate ducting, gas supply and distribution equipment, will be used. In the area of the main LH_2 tank, the booster-orbiter thermal interface will be simulated (if required); the hydraulic lines and appropriate flow equipment will be used, and REI panels will be provided in select areas to monitor bond-line temperatures. The purge test will be performed with test article orientation consistent with actual pad-hold conditions. The vehicle purge gas system test will be performed during cluster firing article tanking tests to assure adequacy of the purge gas system for use during cluster firing.

Thermal Control Subsystem, Flight Tests

Requirements.

1. Ability of vehicle subsystem to withstand thermal-vacuum and zero-g conditions.

2. Performance characteristics determination of insulation

3. Heater design checkout

4. Thermal model verification

5. Thermal coatings performance characteristics

6. Verification that all subsystems remain within prescribed temperature limits during all mission phases.

Test Configuration. The thermal-vacuum test configuration will consist of the first orbital flight test vehicle. Included in the DFI will be instrumentation capable of monitoring temperatures and pressures at selected vehicle locations. The vehicle's attitude (e.g., rotation) and mission flight time will be constrained by thermal limitations, if required.

6.6.2 Approach on Rationale

The approach taken for TCS verification is shown in Figure 6-16. TCS development at the component level will include such items as special thermal coatings, insulation, heating and cooling devices, vents, and hardware (ducting) for the compartment purge system.

The complexity and criticality of the purge gas system warrant early tests to support analyses and to optimize ducting design. The purge gas supply and distribution test will be conducted to assure the adequacy of the overall system design and to optimize the distribution ducting. The compartment venting test is performed to verify the adequacy of the venting design and the analytical tools used. These tests, the purge gas supply and distribution tests, and the compartment venting tests will be performed at the assembly level.

The vehicle purge system will be tested at the combined subsystem level by using the MPS cluster firing test article (Section 6.1). The purge tests must be performed before static firing of the first orbital flight test vehicles, whereas the vent test must be completed before the first orbital flight. These tests, as well as the initial orbital flight tests (thermal tests under vacuum conditions), will complete certification of the TCS. Thermal tests under vacuum conditions are to be accomplished during the initial orbiter flight. Mission profiles and vehicle attitudes will be constrained during the initial orbiter flights to permit checkout of the TCS, while preventing thermal limits from being exceeded.

6.6.3 Support Requirements

Requirements for support of the ground purge thermal conditioning test program are summarized in Table 6-17.

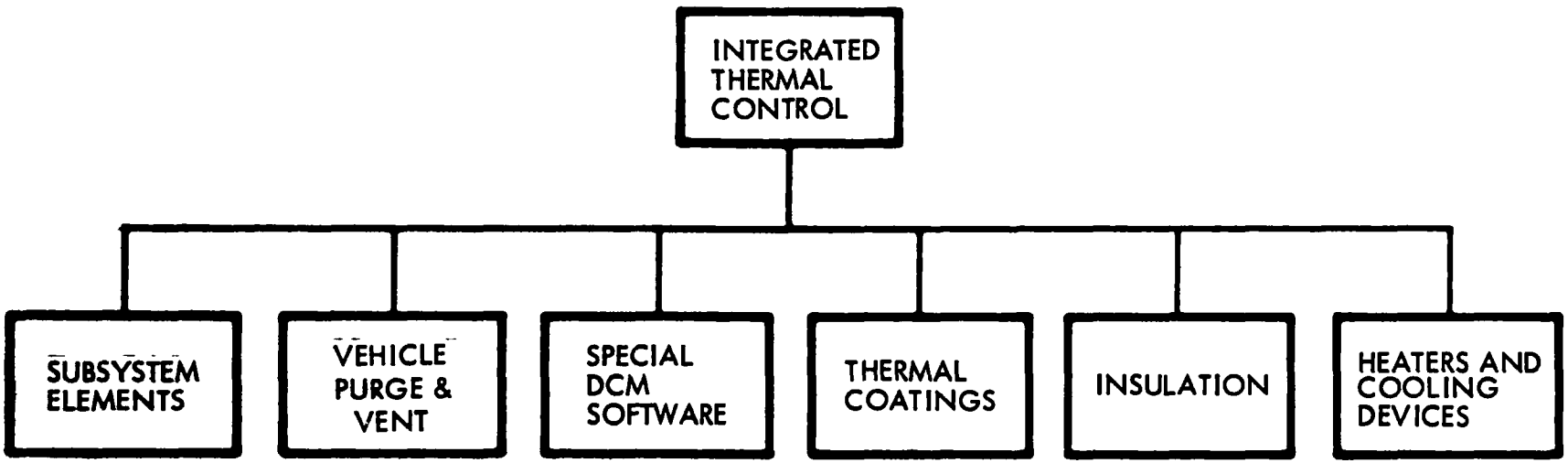


Figure 6-15. Integrated Thermal Control of Orbiter

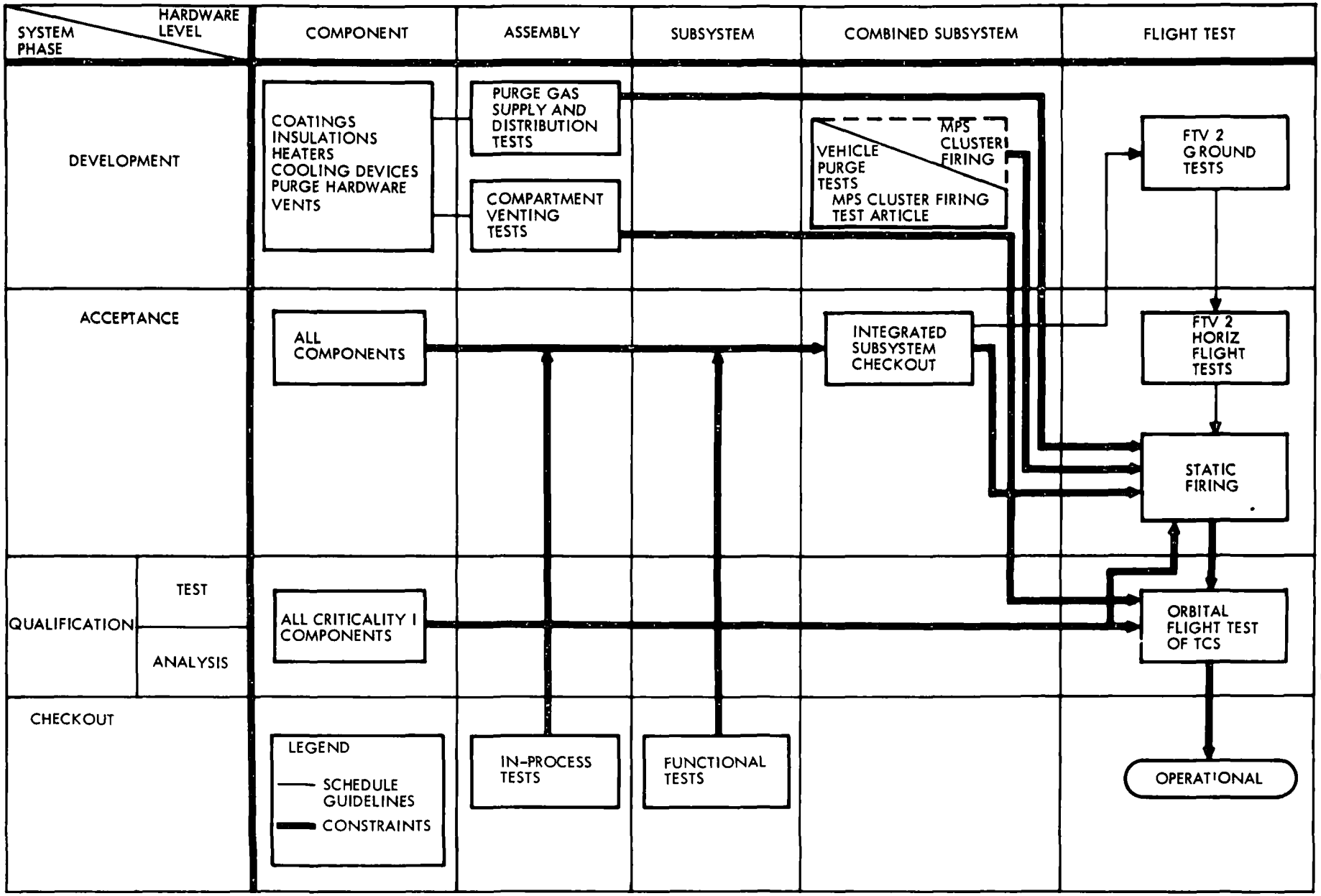


Figure 6-16. Integrated Thermal Control System Test Logic and Constraint Network

Table 6-16. Integrated Thermal Control Subsystem Test Article Requirements

Assembly	Quantity		
	Purge Gas Supply/Distribution Test	Vehicle Purge Test	Compartment Venting Test
Simulated orbiter vehicle (breadboard purge system with mockup of vehicle)	1		
Section of mid-body including simulated ABES engine			1
Entire vehicle		1*	

*MPS cluster firing test article used for this test.

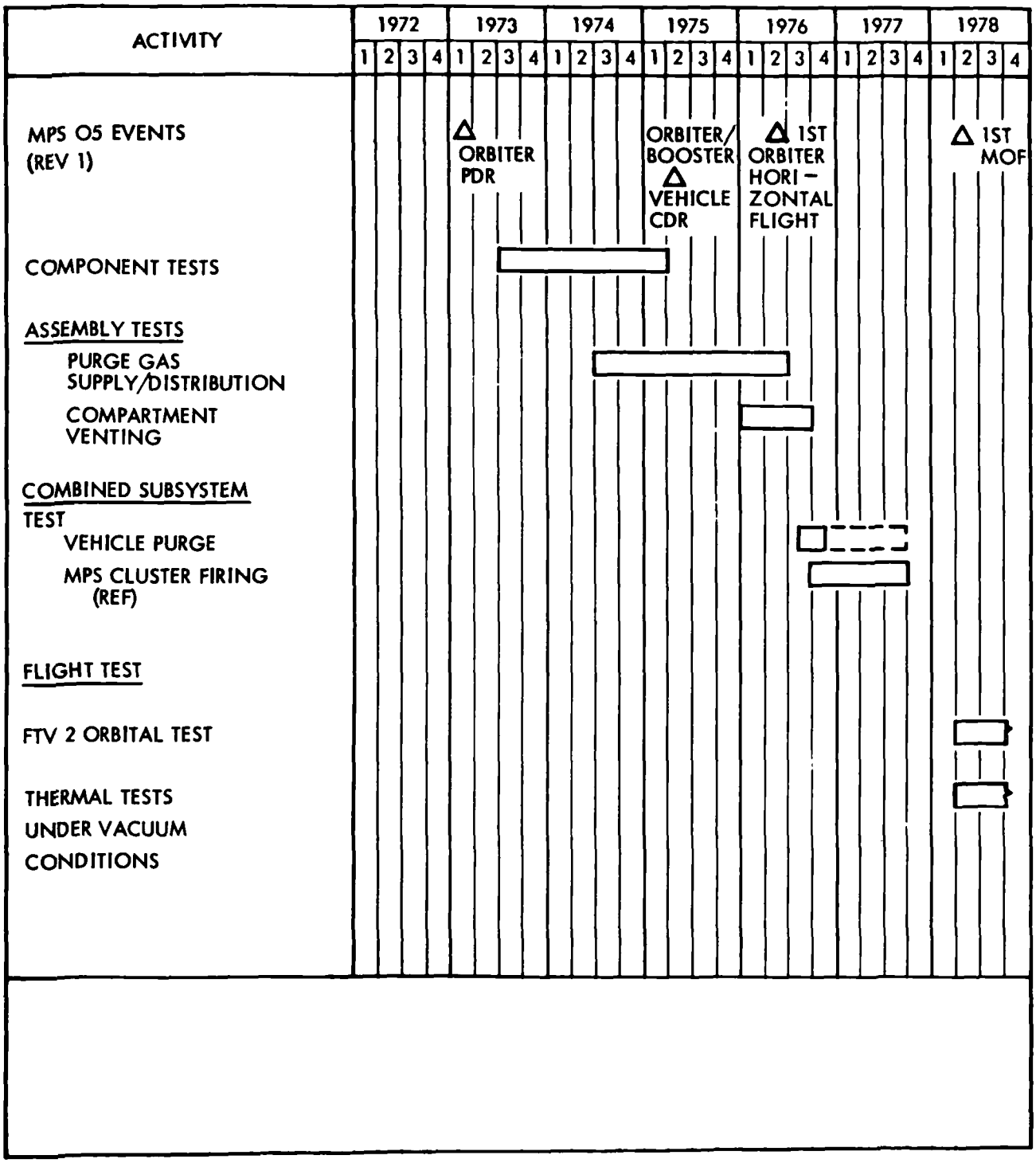


Figure 6-17. Integrated Thermal Control System Test Schedule

Table 6-17. Support Requirements for Ground Purge Thermal Conditioning Tests

Area	Requirements
PURGE SUPPLY/DISTRIBUTION TEST	
Facility	GN_2 storage and supply GN_2 and air temperature and humidity control equipment GN_2 and air distribution equipment Structure to support test article Testing area Electric power
Support equipment	Flow-measuring devices Temperature- and pressure-measuring instruments Recorders
Software	None
VEHICLE PURGE TEST (MPS CLUSTER FIRING TEST ARTICLE)	
Facility	GN_2 storage and supply GN_2 and air temperature and humidity control equipment GN_2 and air distribution equipment Used-gas disposal equipment and ducting Electric power

Table 6-17. Support Requirements for Ground Purge Thermal Conditioning Tests (Cont)

Area	Requirements
VEHICLE PURGE TEST (MPS CLUSTER FIRING TEST ARTICLE)	
Support Equipment	Flow-measuring devices Temperature- and pressure-measuring instruments Recorders Transportation carriers
Software	None
COMPARTMENT VENTING	
Facility	Large vacuum tank with high-rate pumping capacity Supporting structure
Support equipment	Temperature- and pressure-measuring instruments Recorders Transportation carrier
Software	None

6.7 ELECTROMAGNETIC COMPATIBILITY (EMC)

This section describes an overall electromagnetic compatibility test program for the space shuttle orbiter vehicle system elements, subsystems, and combined subsystems.

6.7.1 Configuration

The space shuttle orbiter baseline involves the wide application of digital/solid-state electronics and various types of electrically controlled/activated valves and switches. The solid-state electronics in particular employ high speed, low level pulse type signals and are known to be EMI-susceptible. Many of these functions are safety critical. The reliability of these functions, therefore, is a major concern in a strong electromagnetic and electrostatic field. Electromagnetic compatibility testing shall be performed to demonstrate the ability of all equipment and subsystems to perform with the required effectiveness and without degradation in the total electromagnetic environment encountered during the space shuttle mission.

Radio frequency/electromagnetic interference (RFI/EMI) testing will be accomplished throughout the orbiter systems development and qualification testing to demonstrate adequate design, and to assure that control of potential EMI sources and protective devices for EMI sensitive circuits are incorporated. EMC testing will also provide verification of RF compatibility between all RF systems. The operation of relays and electromechanical valves will also be accomplished to demonstrate that their operation does not inadvertently trigger or adversely affect other circuits

6.7.2 Requirements

The RFI/EMI/EMC certification requirements are listed in Table 6-18 and shall govern all related test activities. The approach and rationale to be used in satisfying these requirements is presented in Figure 6-18. This flow diagram is a development from the requirements presented in Table 6-19.

6.7.3 Approach and Rationale

To enhance the compliance with specified EMI limits, each new electrical and/or electronic assembly will be tested before incorporation into its applicable "black box". The assembled black box will then be tested and its EMI characteristics determined. Successful assembly EMI quality testing will allow proceeding with subsystem testing. The overall integrated avionics will then be tested for EMC on a combined systems level and finally on an integrated vehicle level.

The above tests, except for vehicle postinstallation, apply to certification test hardware. Production hardware will undergo acceptance testing, limited EMI testing as applicable, and EMC as part of the vehicle simulated mission during vehicle integrated testing. Tests at the line replaceable unit (LRU) level and below will generally be performed in laboratories, while system evaluations will generally be conducted on an integrated basis at the vehicle level

Since all avionics subsystems are monitored and controlled by the data and control management (DCM) subsystem via the acquisition control and test units, the digital data bus EMI susceptability tests will be conducted as early in the development phase as possible. In addition, during other system and subsystem compatibility tests, the data acquisition capability of the DCM will be utilized when possible to detect and monitor EMI-induced anomalies.

Requirements for equipment EMC characteristics will be established from system analytical studies. Early in the development phase, equipment level breadboard, evaluation and qualification tests will be performed on new equipment as well as additional EMC tests considered necessary on off-the-shelf black boxes. Results of these tests will be analyzed and used in establishing the requirements for subsequent subsysem and integrated level tests.

EMI susceptability identification and corrections for applicable systems will be implemented into the subsystem before the EMC level test activities. Among the test articles required will be at least one each of all electrical/ electronic components to be developed for this program and those off-the-shelf items determined to require complete or partial retest. It is anticipated that existing certified screen rooms will support this program.

The test articles required will be the same as those that will undergo the normal development testing No additional test hardware will be specifically required for this test program.

All tests will be conducted using procedures based on design specifications and appropriate standards, and designed to demonstrate the ability of the subsystem to function within the prescribed tolerances.

The EMC general acceptance test will be performed on each production vehicle and will be directed primarily to critical areas. These critical areas will be defined by results of the individual EMI tests and mission operational requirements.

An EMC control plan will be formulated to implement the methods by which design guides will be used to avoid practices that may cause serious interference problems and potential program delays. In addition to providing guidelines on design techniques and materials it will also define:

1. The organization responsible for controlling the EMC program and responsibilities and authorities.

2. Requirements for grounding, bonding, shielding, and wire harnessing.

This control plan will be implemented early in the initial design stages and will be in effect throughout the development program. The plan will include the requirements for an EMC acceptance test conducted on an integrated system/vehicle level.

In general, the analysis of the data should identify:

1. All EMI emitters and receptors

2. Power and sensitivity levels

3. Coupling paths

4. Total electromagnetic energy

The requirement of "no system malfunction" shall be considered to have been met when the sum of all extraneous electromagnetic energy that may be introduced into the most critical point of a system is at least 6 DB below the operating threshold levels of the subsystems elements.

Table 6-18. Electromagnetic Compatibility Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
1. Compatibility of off-the-shelf "black boxes" with other equipment in each subsystem.					P	S	S
2 Demonstrate subsystem compatibility with all other systems.						S	P
3 Demonstrate system compatibility with its ground support equipment.	S						P
4 Demonstrate compliance to EMC designs requirements including all approved safety margins.	S						P
5 The vehicle equipment subsystem functions properly with the acceptable limits of the vehicle/GSE electrical power source.						S	P
6. Demonstrate that all electrical/electronic equipment installed or associated with the vehicle system meets the transient, radiated, and conducted susceptibility limits established for this program.			S				P
7 Proper power quality as delivered by the electrical power generation and distribution systems – vehicle and ground support equipment.							P
8 Demonstrate that the critical circuits operate normally and that they are within the approved degradation criteria and safety margins electroexplosive devices and systems whose degradation affects safety of flight or mission success.							P
9 The adequacy of all shielding, bonding, grounding, and routing						S	P
10 Susceptibility to low frequency noise of unbalanced circuits/ coaxial cables is within acceptable tolerances			S				P
11 Obtain the signature of the RF radiating systems					S		P

Table 6-18. Electromagnetic Compatibility Certification Requirements (Cont)

Certification Requirement		Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
12	All harnessing is addressed to prevent signal attenuation and perturbation from cross-talk and interference			S				P
13	Emitted RFI from oscillators and switching networks does not cause inadvertent system operation			S				P
14	Signal level differentials between adjacent cables do not cause intolerable crosstalk					S		P
15	Susceptability of unbalanced circuits to EMC through the ground path is within tolerance and does not present a coupling problem when a common chassis is used for the signal return path							P
16	Transients caused by circuit keying and radiated or conducted through cables do not have adverse effects on other circuits						S	P
17	Demonstrate compatibility at the interface of the facility and the vehicle							P
18	Engineering specifications, engineering drawings, and production drawings are in compliance with the interference control requirements plan.	P						
19	Adequacy of arc suppression associated with switching of inductive loads						P	S
20	AC and dc input power quality is in conformance with the equipment requirements These requirements shall include limits on long term voltage variations, amplitude, transients, and ripple						P	S

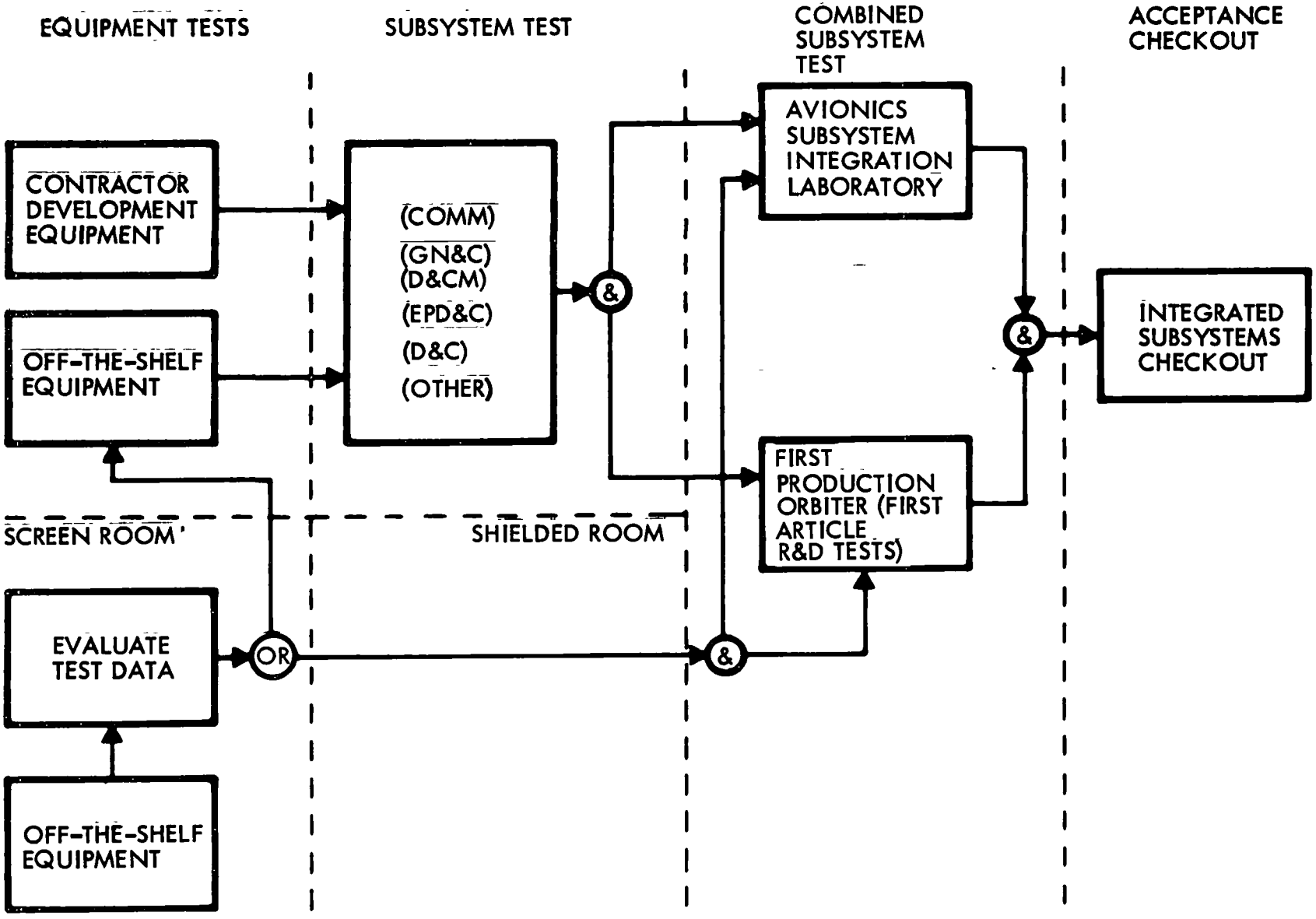


Figure 6-18. Electromagnetic Compatibility Test Logic Diagram

6.8 STRUCTURAL DYNAMICS TEST PROGRAM

6.8.1 Configuration

Structural dynamic testing involves elements of the structures, flight control, and propulsion subsystems. The testing ranges from small subscale models to the complete vehicle. The test configuration is therefore dependent upon the specific objectives to be satisfied.

6.8.2 Requirements

Structural dynamics tests are performed to satisfy several objectives: to provide data for use in analytical studies, to confirm results of such studies, to verify predicted dynamic environments, and to evaluate the capability of structure and equipment to withstand these environments. The certification requirements are listed in Table 6-20. General requirements are to certify that:

1. The structure possesses adequate stability margins to avoid flutter instabilities.

2. The combined structure/propulsion system possesses adequate stability margins to avoid longitudinal oscillation instability (pogo).

3. The combined structure/flight control/propulsion system has no adverse coupling characteristics (due to such excitations as gusts, sloshing, control inputs, noise, turbulence, or thrust variations) that could impair structural integrity or performance.

6.8.3 Approach and Rationale

The general sequence of testing uses models in the early design stage to confirm initial analytical results, followed by tests on components and assemblies for improved data to check interim study results. The final calculated design data are then confirmed by tests on the actual vehicle in ground and/or flight operations (Figures 6-19 and 6-20).

Aeroelasticity and Dynamic Loads

This category covers the testing required to support analyses for flutter, static aeroelasticity, and dynamic loads due to a variety of transient and steady-state excitations including ground winds, liftoff hold down and release, gusts and turbulence, high dynamic pressure, thrust transients, staging/separation, docking, entry, cruise flight maneuvers, landing, and taxiing. Model tests planned by NASA Langley will be used to initially

confirm modes of the mated vehicle and thus verify the flexibility characteristics of the attachment/separation system. Wind tunnel model tests will be conducted on the mated vehicle to investigate such ground winds phenomena as vortex-shedding, galloping, and stop-sign flutter Orbiter aerodynamic surface models (wing-elevon and fin-rudder) will be vibration-tested for modal confirmation and then wind tunnel tested at high subsonic, transonic, and low supersonic speeds to investigate flutter tendencies Utilizing flutter boundary data from the component flutter model tests, an orbiter flutter model will be fabricated and tested in the more critical flight regimes. Tests will be conducted at high angles of attack to investigate stall flutter and buffet tendencies. This model will be designed to permit mating with a booster model to also conduct a flutter model test of the mated configuration in the ascent flight mode. Assembly and subsystem tests for flutter purposes are limited, since the entire vehicle is usually involved. One such test program will investigate panel flutter boundaries for typical structural panels.

Studies of the current design configuration and trajectory profiles indicate the critical flutter regime occurs during boost at maximum q and relatively low structural temperatures. During entry, the higher temperature profile (with an attendant approximate 10-percent loss in modulus), combined with a relatively low q, is considered less critical for flutter Therefore, wind tunnel models for elevated temperature tests are not considered a requirement of the flutter model test program

Calculated data will be confirmed by determining stiffness coefficients for the orbiter wing and vertical tail on the static test structure. Similar tests are needed on the attachment separation system, thrust backup structure, and landing gear attachments to verify calculated stiffness data.

A major ground vibration test (GVT) program is required to verify analytically determined vehicle modes and damping characteristics of the orbiter and booster in the mated and unmated configurations. These tests will determine axial, torsional, lateral, and vertical bending modes of the orbiter and mated vehicle, providing a foundation for subsequent dynamic load and stability studies The orbiter GVT will be conducted on a flight vehicle, before the first horizontal flight, in a horizontal attitude using a low-frequency suspension system. A mated vehicle horizontal GVT will be conducted on the booster and orbiter flight vehicles before the first vertical flight to confirm analytical predictions of the coupling effects on modal response and damping.

Finally, the horizontal and vertical flight test programs will include measurements to determine flight air loads, bending moments, and local acceleration response to turbulence, maneuvers, staging, landing impact, and etc. The ability to conduct flight flutter tests on the shuttle vehicles during

horizontal flight tests is limited by performance limitations with the air breathing engine system (ABES).

Pogo

Pogo testing involves a coupling of the structural system with the main propulsion system to obtain component, subsystem, and complete vehicle data for analysis confirmation. Test data are also needed to support the development of a pogo suppression system.

Model tests will provide early information on the degree of lateral-axial structural mode coupling induced by the asymmetrical nature of the shuttle vehicle. These tests may also provide insight into the potential problem of liquid sloshing coupling with the LO_2 tank/fluid axial modes.

Tests of engine system components during manufacture will furnish data needed to develop an early mathematical model of the engine. Fluid dynamic flow in lines, pumps, preburners, and injectors will be evaluated. Also early confirmation of dynamic characteristics of a pogo suppression device will be obtained. Vibration tests will be performed to obtain axial modes of the orbiter LO_2 tank with varying fluid levels.

Subsystem testing confirms analytical modes used in various studies. The structural static test vehicle will be used to determine thrust structure stiffness for comparison with finite element calculations Testing of structure/propulsion subsystem assemblies (such as the feed line/pump interface) is of extreme importance, since accurate analytical modeling of this interface is almost impossible without test-derived data The dynamics of fluid flow from the bottom of a tank, through a feedline, into and out of pumps, and into the engine itself must be measured under a variety of engine operating conditions. Tests under both cold and hot (firing) flow conditions will be performed, in some cases with supplementary pressure "pulsing" or mechanical excitation. Engine transfer function data, relating inlet pressure variations to thrust oscillations and pump dynamic gain (change in pump discharge pressure with inlet pressure variation) are derived from these tests. Effectiveness of Pogo suppression devices will also be evaluated in subsystem tests.

Verification of pogo analysis results and mathematical models used to obtain those results require several types of tests of full scale vehicles. Vehicle axial modes and damping should be confirmed by a vertical vibration test at a number of propellant tank fluid levels. The feasibility of conducting a mated vehicle vertical GVT on the booster and orbiter to provide coupling effects earlier in the program than the proposed mated horizontal GVT will depend upon final selection of test articles, schedule, and availability of a suitable test site. Final confirmation of local or components modes and

structural response of interest, such as the engine thrust structure and the LO_2 tank bulkhead at various liquid levels, will also be obtained in the modal test. Component modes and responses will be evaluated on the clustered static firing vehicle. However, it is not probable that complete vehicle axial modes can be obtained from this test The static firing tests of single clustered engines will also provide data on the behavior of the feedline/pump/engine system with and without a suppression system in operation. Flight test operations using the main propulsion system will be instrumented to obtain data on any pogo tendencies.

Shock, Vibration, Acoustics

Test programs in this category are designed to verify predicted dynamic environments and to determine response of local structure and equipment for confirmation of design criteria. Initial aerodynamic noise predictions will be checked by wind tunnel model tests in which pressure fluctuations are measured at various locations on the orbiter and the mated configuration. Rocket engine noise and cruise engine noise will be measured in static firing tests of individual engines. These data will be used to establish acoustic test levels for application to large structural sections of the orbiter: the crew compartment, and the mid-aft body, including the payload bay. Structural response will be compared to calculated values and response of selected items of equipment will be monitored for verification of their ability to withstand the applied environment. Similar tests will be run to assure that internal acoustic levels in critical areas are within specified limits. Sonic fatigue tests will be conducted on typical panels exposed to the ABES noise field to certify exposed structure for its predicted life-time exposure times an appropriate scatter factor. Additional tests will be conducted on critical panels for buffet effect design criteria.

Full scale vehicle testing for shock, vibration, and acoustic purposes consists of clustered firing data to confirm predicted liftoff noise levels and in-flight measurements for verification of other vibroacoustic environments The latter include boundary layer noise data, pressure fluctuations in interference and separated flow regions, cruise engine noise, and acceleration data at key locations from acoustic excitation and from mechanical vibration. Finally shock spectra will be obtained during separation system operation, ABES deployment, and landing impact,

6.8.4 Support Requirements

Aeroelasticity and Dynamic Loads

Models for flutter and ground wind studies will be tested in wind tunnels at NASA Langley and Ames Research Center. The Langley 16-foot dynamics tunnel has been used for extensive ground winds and flutter model work.

The Ames 11- by 11-foot transonic tunnel has also been used for early flutter model tests. Supersonic flutter tests can be accommodated at Tullahoma. Large scale models for modal investigations will be vibrated in the Langley Dynamics Laboratory.

Stiffness tests will be conducted on surfaces of the static test vehicle. Normal laboratory instrumentation, recording, and data processing equipment will be needed to conduct the test program. Fixtures and supporting jigs will be available as part of the planned static structure test program.

The ground vibration test program to determine vehicle modes, frequencies, and damping requires extensive setup preparation. A multiple shaker arrangement, with associated electronic power and control systems, will be required. Instrumentation requirements will include velocity and acceleration transducers as well as data recording and processing equipment. In addition, special low-frequency air suspension systems will be required for supporting the orbiter and mated orbiter/booster configurations in a horizontal attitude.

Pogo

The large scale model for modal measurements will be tested at NASA Langley as previously discussed. Test results are important to dynamic loads and flutter studies as well as for pogo calculations.

Early propulsion system component type test measurements will be made at the engine manufacturer's facility during normal development operations. Pulsing tests using feedline, pump, and engine will be conducted at the facilities supporting hot firings. Modal testing is recommended for MSFC where similar tests have been conducted during the Saturn program Stiffness data for the thrust structure will be obtained from the structural static test program.

Additional instrumentation for pogo-related response data will be provided for use during the clustered firing program. Similarly, inflight measurements for pogo data are part of the normal flight test program and no special facilities are required.

Shock, Vibration and Acoustics

The 2-percent model test is to be run in the NASA/Ames 11-foot transonic tunnel or the NASA/Langley 16-foot tunnel to get data in the M = 0.80 to 1.2 region. Hypersonic data (M = 7 to 10) will be obtained from tests in the AEDC 50-inch diameter facility and/or the NASA/Ames 3.5-foot tunnel. Smaller models for hypersonic studies may be required due to flow blockage problems. Miniature pressure sensors will be flush-mounted on

each model. A data recording system and modern real-time power spectral analysis and plotting equipment will be required Frequency response of each channel must be obtained.

Acoustic tests of most components will require a reverberant chamber which can accommodate articles up to 48-by-54-inches. The larger components require exposure to levels up to 157 dB in an acoustic chamber which can accommodate specimens up to 17-by-14-by-14 feet Panels which may require testing to 171 dB to simulate cruise engine noise will have to be tested in a jet engine test cell. Instrumentation for measuring, and in some cases controlling, noise levels, vibration, and strain will be needed The exact number of instruments depends on the specific configuration and purpose of the test. Data analysis will generally be restricted to narrow band random spectra for acceleration and strain, and one-third octave and narrow band for noise. Capability to simulate mission thermal environments will also be required.

The major structural section vibro-acoustic tests on the crew compartment and the mid-aft body section will require very large acoustic test facilities. Typical of those under consideration are the following three: NASA/MSC 160 kw facility with a 75-by-45-by-35 foot volume and 156 dB overall capability, Wyle/Huntsville chamber (80 kw of acoustic power) with an overall SPL of 154 dB and a 55-by-45-by-35 foot space, the AFFDL facility at WPAFB with 65-by-50-by-35 foot volume and 1 mw of acoustic power. Instrumentation systems for these facilities may require up to 500 data channels, but a trade-off of channels versus a switching concept is possible. Acoustic noise and vibration acceleration and strain are the desired parameters to be recorded.

Measurement programs to obtain data from the clustered engine firing program and from flight test operations include transducers, a data acquisition system (telemetry, onboard, and hardwire), and a rapid, high capacity data processing capability.

Table 6-19. Structural Dynamics Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
AEROELASTICITY AND DYNAMIC LOADS							
1 Stiffness of aerodynamic surfaces (flutter and aeroelasticity)	S			P			
2 Stiffness of attachment and separation system	S	S			P		
3 Modes of aerodynamic surfaces		S					P
4 Ground winds stability and loads	S	P					
5 Vehicle modes and damping (vertical and lateral)		S					P
6 Vehicle response to transient excitation (lift-off, gust, separation, landing, etc.)		P					S
7. Vehicle airload distribution for loads and aeroelastic effects		P					S
8. Vehicle flutter stability (mated and separated)	S	P					S
9. Panel flutter stability		S	P				
POGO							
1. Axial-lateral coupled modes and damping (mated vehicle)		S					P
2 Thrust structure stiffness	S				P		
3. Thrust structure modes		S					P
4 LOX tank/fluid axial modes		S		P			S
5. Main propulsion system component fluid dynamic flow characteristics (pumps, injector, preburners, lines, etc)		S	S		S	P	S
6. Feedline/pump fluid dynamics interface		S			S	P	

Table 6-19. Structural Dynamics Certification Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
POGO (Cont)							
7 Engine transfer function (for POGO analysis)		S			S	P	S
8 Axial modes and damping		S				S	P
9 Pogo suppression system		S	S		S		P
10 Pogo stability		S					P
SHOCK, VIBRATION, AND ACOUSTICS							
1. Pressure fluctuations and aerodynamic noise	S	S					P
2 Rocket engine noise	S				S		P
3. Cruise engine noise	S				S		P
4 Local structure and equipment response to vibro/acoustic excitation	S		P		P		S
5. Internal vibro-acoustic levels in critical areas	S				P		S
6. Mechanical vibration environment	S		P		P		S
7 Sonic fatigue and buffet panel tests	S		P				

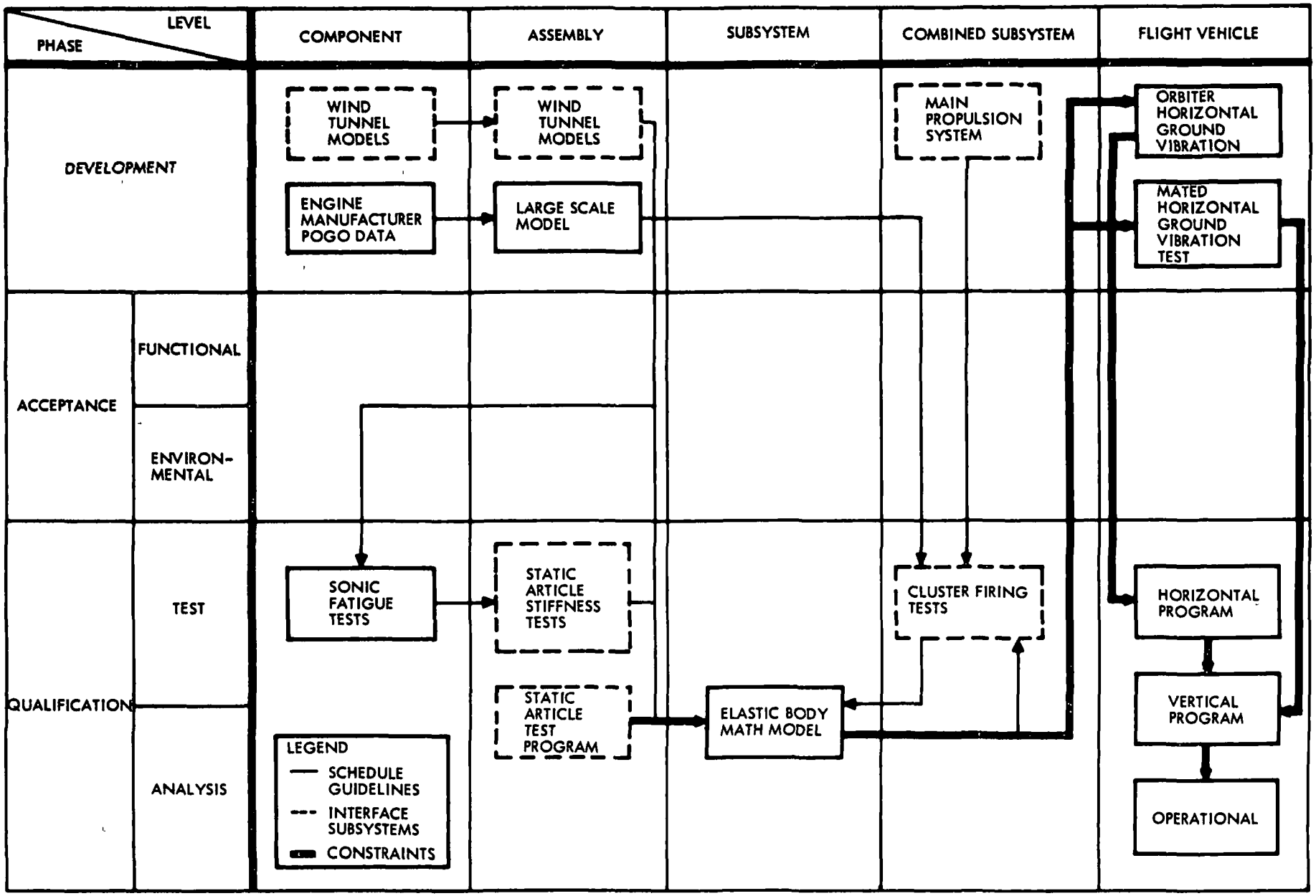


Figure 6-19. Structural Dynamics Test Logic and Constraint Network

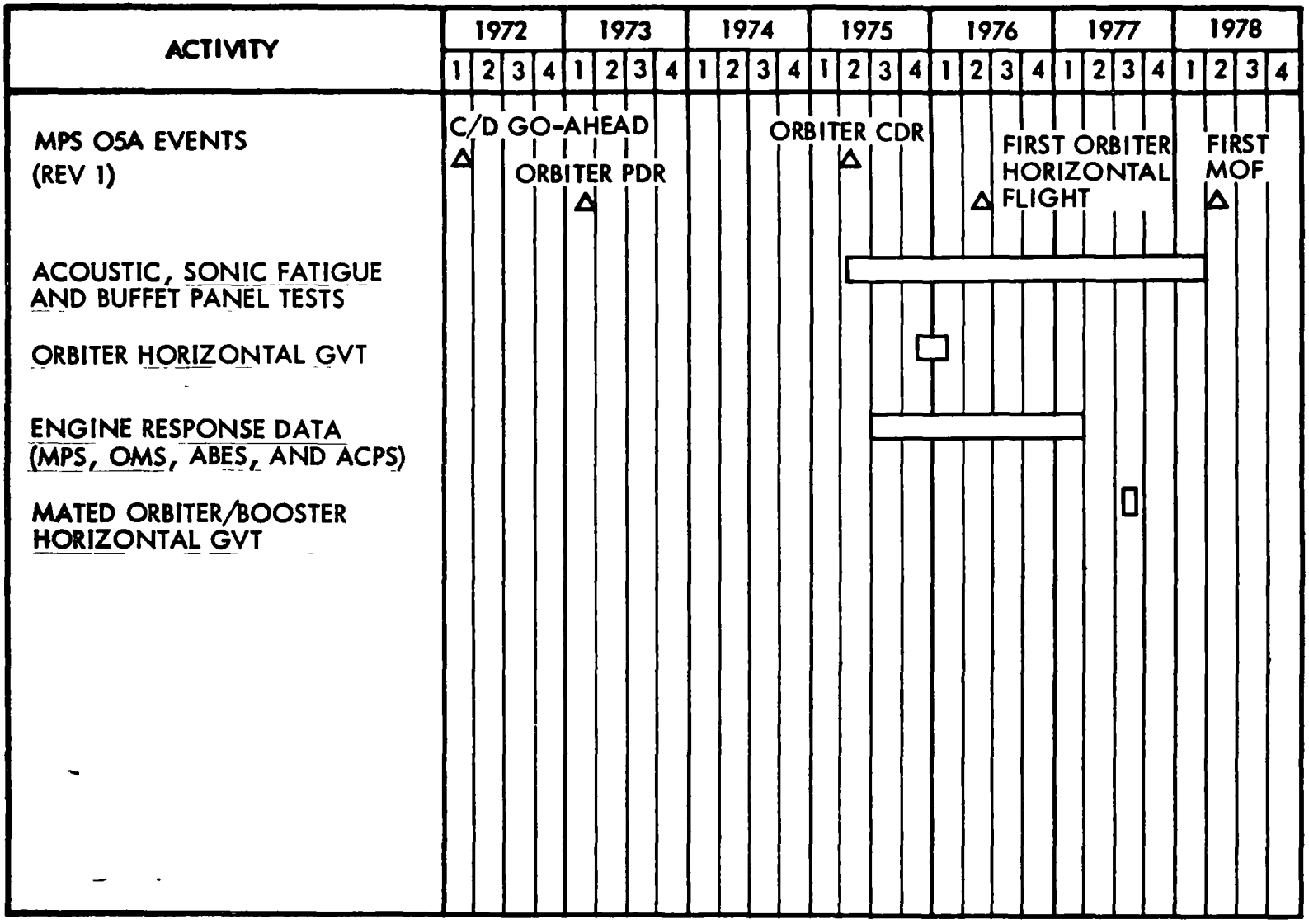


Figure 6-20. Structural Dynamics Test Schedule

6.9 MOCKUPS AND SIMULATION

6.9.1 Mockups

Mockups will provide data in three-dimensional detail that cannot be provided in any other manner. They will provide the opportunity to show man/machine relationships, the relationships of the avionics compartment to installed equipment, the cooling and power installations, the accessibility and placement of equipment, and the location of various crew accommodation facilities. In addition to the human factors aspects, demonstration of easy maintainability and serviceability will be portrayed. On the external portion of the mockups, detail design demonstrations showing the installation of the REI panels, their mounting structure, and underlying insulation will be shown. In the engine section, the most satisfactory utilization of space and the simulation of line routing, disconnect panels, engine gimbal clearance, etc., will be accomplished. Several models and soft and hard mockups are required for human factors engineering testing. They are described in Section 5.13. Specific requirements and program plans for additional mockups are under study.

6.9.2 Flight Simulator

Simulation is firmly established as a necessary and economically justifiable activity that takes its place alongside analysis, wind tunnel, design, and flight test. The flight simulation program will provide direct support to the design and development of the orbiter vehicle in regard to navigation, guidance, and flight control system. The simulator has 6 degrees of freedom with a fixed base and is a closed-loop, hybrid type for man-in-the-loop studies. Subsystem simulations will consist of guidance and control, body dynamics, man-machine integration, consumables accounting, and/or management and propulsion systems. Flight phase efforts will include simulation of entry, boost, aborts, landing, rendezvous, docking separation, interceptions, and navigation. A complete description of the simulator facilities is given in Volume 1 of the Facility Utilization and Manufacturing Plan for Phase C/D.

7.0 VEHICLE TEST

This section covers the orbiter vehicle acceptance and postcheckout, preflight, and flight testing activities. The flight test description includes the horizontal subsonic testing of the orbiter vehicle. Although mated ground and flight tests are described in Volume I of the Preliminary Test Plan, Table 7-1 of this volume provides a listing of the subsystem test requirements to be satisfied during the total flight test program. The requirements are categorized by mission mode, test requirement, subsystem affected, and critical parameter. These requirements have been restructured and are listed within the respective elements of the flight test program.

7.1 ORBITER VEHICLE 1

Orbiter 1 is the first vehicle to be delivered from Manufacturing to support the flight test program. Figure 7-1 depicts the vehicle flow and schedule from postmanufacturing integrated checkout through the horizontal flight test program to refurbishment for operational flights.

7.1.1 Vehicle Configuration

The vehicle will be used in the horizontal subsonic phase of testing, then will be modified to be utilized in mated orbital flight. To permit overall subsystem evaluation during the takeoff, cruise, and landing phases, the vehicle is to be configured the same as for operational flight except for the following changes

Main Propulsion Subsystem

Main propulsion subsystem (MPS) engine delivery schedules indicate that operational engines will not be available for installation during the initial horizontal flight test phase. Therefore, the MPS will be replaced by a unit which, although inoperative as a rocket engine, provides the actual interfaces, mass properties, and external shape.

Fifth Air-Breathing Engine

The ABES includes a fifth engine for the baseline ferry configuration. The fifth engine will be used for the majority of the horizontal flight test program primarily to provide increased safety for the takeoff and landing phase and secondarily to provide a larger flight envelope. This engine will be removed to evaluate and demonstrate those performance, stability, control,

Table 7-1 Flight Test Requirements

Mission Mode	Subsystem	Requirement	Critical Parameters
Ascent	Orbit maneuvering	Confirm maintenance of OMS system in an engine start condition	Engine inlet temperature and pressure Tank pressure and temperature
	Main MPS	Verify engine prestart propellant requirements, verify extent of tank prepress decay	Ullage pressure
	APU subsystem	Confirm analysis and development test results of system installation tolerance to vehicle dynamics	Vibration, acoustics
	Hydraulic	Confirm analysis of flight control surface holding hinge moment	Hinge moment
		Confirm analysis of static stiffness and surface natural frequency	Surface flutter
		Verify vibration and acoustic analysis on equipment	Frequency g level
	Structures (loads and response)	Confirm calculated flight loads (accelerations, and strains) at many critical orbiter locations	Strain and acceleration at selected locations
	Structures and propulsion (pogo)	Confirm orbiter vibratory response to booster SSME thrust oscillations, and verify pogo-free operations	Acceleration time history at selected locations Fluid pressure fluctuations, thrust fluctuations, engine performance parameters
	Structures (shock, vibration, and aeroacoustic)	Confirm predicted aeroacoustic noise for flow interference region, behind cockpit, wing surfaces, cargo bay, etc	Flight trajectory parameters
		Confirm predicted vibrations at many critical locations throughout orbiter	Vibratory accelerations
	Structures (flutter and aeroelastic)	Confirm the results of aeroelastic analysis and flutter model tests on the aerodynamic surfaces and TPS panels of the orbiter-booster combination	Accelerations at selected points
	Integrated system performance (flight mechanics)	Demonstrate capability of vehicle to deliver payload into orbit	Combined performance of critical system, e g , propulsion guidance and control separation

Table 7-1 Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Ascent	TPS	Certification of TPS design data by verifying predicted aerothermal environment	Aerodynamic heating to vehicle including booster interference and basic recirculation heating during engine firing
	Thermodynamics	Confirm structural temperature and temperature gradients during boost	Temperature
		Confirm internal vehicle temperatures and response.	Temperature
	Crew systems	Confirm analysis and ground test results of orbiter internal acoustic environment	Sound spectral density analysis at crew and equipment positions
			DB versus frequency
		Confirm analysis and ground test results of orbiter crew compartment vibration levels.	Frequency and amplitude at selected crew interface areas and storage space
	Aerodynamics	Verify air loads.	
		Confirm O+B dynamics (control orbit).	
		Verify compartment venting.	
	Flight control	Verify failure correction capability of digital fly-by-wire flight control system.	Failure modes
			Flight condition, i e , q, h, M_N
	Electrical power generation	Confirm analysis and static test results of fuel cell water separation and transfer	Orientation and acceleration loads
		Confirm analysis and development test results of system installation tolerance to vehicle dynamics.	Orientation, vibration, acoustics and acceleration
		Confirm critical component environment thermal control	Atmospheric heating, heat generation, and transfer
		Confirm reactant storage vacuum integrity	Vibration, acoustics, acceleration and thermal

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirements	Critical Parameters
Ascent	Electrical power generation (cont)	Confirm reactant storage and distribution fluid expulsion and pressure control	Thermal and flight load
	Attitude control propulsion system/orbit maneuver system	None	
	Aerodynamics	Confirm analysis and wind tunnel test results of orbiter/booster shock impingement Confirm air loads, estimates, magnitudes, and distributions	Trajectory parameters, altitude, velocity, mach number, and atmosphere profile, vehicle attitude, pitch, roll, yaw, control surface deflections and booster engine gimbal angles, primary parameters are vehicle surface pressure loads and distribution, surface pressure taps required
		Confirm orbiter plus booster dynamics	Trajectory parameters, altitude, velocity, mach number, and atmosphere profile, vehicle attitude versus time (pitch, yaw, roll), vehicle attitude rates, control surface deflections and booster engine gimbal angles, vehicle accelerations, thrust vector and control surface command inputs
		Requirement exists to verify compartment venting analytical predictions	Trajectory data versus time, internal compartment pressures versus time, external pressures versus time, bursting pressures become critical
	Structures	Confirm net pressure acting on primary structure for nominal and off nominal boost and entry conditions	Boost and entry external pressure profile to obtain the actual delta pressures acting on the TPS and on the primary structures
Separation	Orbit maneuvering	Confirm maintenance of OMS system in an engine-start condition.	Engine inlet temperature and pressure, tank pressure and temperature

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Separation	Main MPS	Verify engine-start transients slump in LO_2 inlet, thrust buildup rate, ullage pressure.	Engine inlet pressure, engine chamber pressure, LO_2 and LH_2 tank ullage pressure, engine pump discharge pressure
		Determine environmental effects during main engine operation.	Temperature (structure, heat-shield)
		Determine pogo suppression system performance	All engine pressure structure accelerations
	APU subsystem	Confirm analysis and development test results of system installation tolerance to vehicle dynamics.	
		Confirm subsystem engine gimbal loads.	Separation dynamics vehicle trajectory, reactant consumption
	Structures (loads and response)	Confirm calculated separation loads.	Strain/acceleration/shock loads at selected locations
	Structures (shock, vibration, aeroacoustics)	Confirm calculated separation transients	Transient accelerations
	Integrated system performance (flight mechanics)	Demonstrate capability of vehicle to deliver payload into orbit	Combined performance of critical system, e.g., propulsion, guidance, and control separation
	TPS	(See Ascent mission mode)	
	Crew systems	(See Ascent mission mode)	
	Aerodynamics	Verify dynamics (loads, attitudes).	
	Flight control	(See Ascent mission mode)	
	Electrical power generation	(See Ascent mission mode)	
	Attitude control propulsion system	Provide vehicle stabilization during separation	Relative positions — booster, orbiter

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Separation	Aerodynamics	Verify dynamics loads and vehicle attitudes	Trajectory data versus time, vehicle attitude and accelerations, accurate velocity and acceleration data, relative positions of orbiter and booster, photographic data
Orbit Injection	Orbit maneuver	Verify engine-start transient and standby state operation	Engine inlet pressure and temperature, LO_2 and LH_2 tank ullage pressure, turbopump discharge pressure engine chamber pressure
	Main	Determine propellant residuals (PU system performance)	Propulsion quantity
		Determine engine-cutoff transients stratification.	All engine measurements
			Propellant temperature
	APU subsystem	(See Separation mission mode)	
	Hydraulic	Verify the gimbal rates and loads established by analysis and hot firing tests are sufficient to provide adequate flight control during two-engine operation.	Rate gimbal moment
	Structures (loads and response)	(See Ascent mission mode)	
	Structures and propulsion (pogo)	Confirm orbiter SSME pogo-free operation	(See Ascent mission mode)
	Structures (shock, vibration, aeroacoustic)	Confirm predicted SSME mechanically transmitted vibration	Vibratory accelerations engine performance parameters
	Integrated system performance (flight mechanics)	(See Ascent mission mode)	
	TPS	(See Ascent mission mode)	

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Orbit Injection	Crew systems	(See Ascent Mission mode)	
	Flight control	(See Ascent mission mode)	
	Electrical power generation	Confirm analysis and static test results of fuel cell water separation and transfer	Orientation acceleration loads
		Confirm critical component environment thermal control.	Atmospheric heating, heat generation, and transfer
	Attitude control propulsion system	None	
Orbit	Orbit maneuver	(See Orbit Injection mission mode)	
	Main	Confirm retention of main tank pressure for recovery.	Ullage pressure, ullage temperature
	APU subsystem	Confirm critical component environment thermal control	Cold temperature (vehicle orientation)
		Confirm startup and operation in zero-g environment	Zero-g, vacuum, temperature
		Verify reactant consumption	Vacuum, tempe-ature, leakage flow, surface operations
	Hydraulic	Verify thermal analysis of entire system	Temperature, -65 to +275F
		Verify cargo system rates analysis	Rates
	Structures (loads and response)	Confirm docking response at several critical orbiter locations. Must be performed during flights to space station	Local accelerations
	Structures and propulsion (pogo)	Confirm orbiter OMS pogo-free operation	(See Ascent mission mode)

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Orbit	Structures (shock, vibration, aeroacoustics)	Confirm predicted OMS engine mechanically transmitted vibrations	(See Orbit Injection mission mode)
	Integrated system performance (flight mechanics)	Confirm docking maneuver	Attitude control
	Thermodynamics	Confirm structural temperature and temperature gradients during cold and hot-soak orientation	Temperature
		Confirm internal vehicle temperatures and response	Temperature
	Crew systems	(See Ascent mission mode)	
	Flight control	(See Ascent mission mode)	
	Electrical power generation	Confirm analysis and static test results of fuel cell water separation and transfer.	Zero g, cold temperature low flow rates
		Confirm critical component environment thermal control.	Cold temperature and cyclic temperature
		Confirm fluid dynamics, heat transfer and general system operation.	Zero g, vacuum and temperature
		Confirm reactant tankage heat-leak performance	Temperature, vacuum, and zero g
		Verify input data for consumables analysis computer program.	Environment, loads duty cycle, and specific reactant consumption
		Confirm fuel cell inflight shutdown and start procedures.	Interface sequence and conditions, environment, and start characteristics
		Confirm absence of stratofication in reactant storage vessels	Zero g, fluid, and thermal dynamics effects

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Orbit	Electrical power generation	Confirm emergency reactant storage vessel depletion	Interface sequence and conditions, environment and space-vacuum heat leak
		Confirm fuel cell H_2 vent, O_2 purge, and H_2O vent.	Vacuum, thermal, and zero-g
	Attitude control propulsion system	Docking - space station and alternate payloads	Relative position and closing rates
Entry	Orbit maneuver	Verify engine installation compatible with reentry heating and structural loads.	Temperature
	Main	Verify engine nozzles will withstand heating and and structural loads.	Temperature
		Verify tank pressure regulation (venting during heatup).	Ullage temperature, ullage pressure
	APU subsystem	Confirm analysis and development test results of system installation tolerance to vehicle dynamics	Vibration, acoustics, acceleration
		Confirm startup and operation in zero-g environment.	Zero-g, vacuum, temperature
		Confirm critical component environment thermal control	Vehicle trajectory temperatures
		Verify reactant consumption	Vehicle trajectory leakage flow, surface operations
	Hydraulics	Verify analysis and wind tunnel test results of flight control surface hinge moments and rates.	Hinge moment and rates
	Hydraulics	Verify capability of flight control with loss of 1/3 hinge moment	Hinge moment and rates
		Verify flutter analysis of flight control surfaces.	Surface flutter
		Verify analysis of speed-brake capability.	Hinge moment and rate

Table 7-1 Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Entry	Structures (loads and response)	(See Ascent mission mode)	
	Structures (shock, vibration, aeroacoustics)	Confirm predicted aerodynamic noise for several locations	(See Ascent mission mode)
		Confirm predicted vibration at many critical locations throughout orbiter	(See Ascent mission mode)
	Integrated system performance (flight mechanics)	Demonstrate capability of vehicle to deliver payload from orbit to selected landing site	Combined performance of critical systems, e g , guidance, navigation, control, TPS
	TPS	(See Ascent mission mode)	Aerodynamic heating to vehicle
	Thermodynamics	Confirm TPS and TPS penetrations thermal design and performance	Temperature
		Confirm internal vehicle temperature and response during entry soak-back	Temperature
	Crew systems	(See Ascent mission mode)	
	Flight controls	(See Ascent mission mode)	
	Electrical power generation	Confirm analysis and static test results of fuel cell water separation and transfer	Orientation and acceleration loads
		Confirm analysis and development test results of system installation tolerance to vehicle dynamics	Orientation, vibration, acoustics, acceleration
		Confirm critical component environment thermal control	Atmospheric heating, heat generation, and transfer
		Confirm reactant storage vacuum integrity	Vibration, acoustics, acceleration, and thermal

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Entry ↓	Attitude control propulsion system	ACPS performance - plume boundary layer interaction	Vehicle response and control rates
	Aerodynamics	Verify air loads predictions in magnitude and distribution on the orbiter alone	Surface pressure loads Trajectory parameters, and vehicle attitude
		Confirm orbiter dynamics.	Trajectory parameters, vehicle attitudes, control system commands and ACPS utilization
		Compartment venting - verify analytical predictions.	Trajectory data versus time, internal compartment pressures versus time, external pressures versus time, crushing deformations becoming critical
		Verification of aerodynamic control characteristics	Trajectory parameters control surface deflections and resultant vehicle responses
	Structures	Area of concern is TPS panel and primary structure. Confirm vehicle thermal stresses for worst entry condition with temperature distribution over total vehicle from nominal entry condition. Also confirm stresses used in margins of safety and fatigue calculations.	Entry temperature and pressure
		Area of concern is vent system bleed rates Confirm net pressure acting on primary structure for nominal and off nominal boost and entry conditions.	Boost and entry external pressure profile to obtain the actual delta pressures acting on the TPS and on the primary structure

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Transition	Orbit maneuver	None	
	APU subsystem	Confirm analysis and development test results of system installation tolerance to vehicle dynamics.	Vibration, acoustics, acceleration
		Confirm critical component environment thermal control	Vehicle trajectory and temperatures
		Verify reactant consumption	Vehicle trajectory leakage flow, surface operations
	Hydraulics	(See Entry mission mode)	
	Structures (loads and response)	(See Ascent mission mode)	
	Structures (shock, vibration, aeroacoustics)	(See Entry mission mode)	
	Structures (flutter and aeroelastic)	Same as for Ascent mode except for detached vehicle only.	(See Ascent)
	Crew systems	(See Ascent)	
	Flight control	(See Ascent)	
	Electrical power generation	(See Ascent)	
	Aerodynamics	Verify external air loads	Trajectory data, vehicle attitude external pressure magnitudes and distributions
		Confirm orbiter dynamics	Trajectory data, vehicle attitudes and responses to control system inputs, vehicle oscillatory behavior, vehicle static stability
		Compartment venting - verify analytical predictions	Trajectory data, internal compartment pressures versus time, crushing type loads continue to increase

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Transition	Aerodynamics (cont)	Determination of transonic aerodynamics/ control characteristics.	Trajectory data, vehicle attitude and configuration data, vehicle dynamics responses
Cruise	Orbit maneuver	None	
	Propulsion	Conduct horizontal flight test program to demonstrate the dynamic characteristics of the ABES over the entire ferry flight envelope and to greatest extent possible over DRM envelope Demonstrate response characteristics of engine/inlet system over extended vehicle operational modes, go-around recovery maneuver, ferry-cruise compatibility (range).	Thrust reponse fuel system engine compatibility (dynamic) standby and transient, forward body flow field/inlet performance, fuel consumption range capability
	APU subsystem	(See Transition)	
	Hydraulic	Verify analysis and wind tunnel test results of flight control surface hinge moment and rates	Hinge moment and rates
		Verify system thermal analysis.	Fluid temperature +275F
		Verify vibration and acoustic analysis stress on equipment.	Frequency g level
		Verify analysis of static stiffness and surface natural frequency.	Surface flutter
		Verify capability of flight control with loss of 1/3 hinge moment.	Hinge moment and rates
		Verify analysis of engine deployment rate	Time of actuation 10 seconds maximum
	Structures (loads and response)	Confirm calculated cruise loads (e.g , gust response) at several critical orbiter locations).	See Ascent
	Structures (shock, vibration, aeroacoustics)	Confirm predicted ABES engine noise.	(See Ascent)
		Confirm predicted vibration near ABES engines.	(See Ascent)

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Cruise	Structures (flutter and aeroelastic)	Same as Transition	Same as Ascent
	Crew systems	Same as Ascent.	
	Flight control	Same as Ascent	
	Electrical power generation	Same as Ascent	
	Aerodynamic	Verification of air load predictions	Trajectory flight profile data and vehicle attitude and configuration
		Confirm orbiter - dynamics	Flight profile and vehicle configuration ABES power settings, base pressure data, vehicle cruise and dynamic performance data
		ABES deployment transient	Flight profile and vehicle dynamic behavior, vehicle performance prior to, during, and after engine deployment
		Engine out performance/control	Flight profile data and vehicle configuration, vehicle attitude and performance
		FAR compliance	Vehicle performance and handling qualities
Landing	Orbit maneuver	Verify orbit maneuvering system and structural compatibility	Postflight inspection
	Propulsion	See Cruise	
	Main	Verify main propulsion systems structural compatibility	Postflight inspection
	APU subsystem	See Cruise.	

Table 7-1. Flight Test Requirements (Cont)

Mission Mode	Subsystem	Requirement	Critical Parameters
Landing	Hydraulic	Verify nose wheel steering rates and deflections are acceptable for ground handling.	Rate deflection
		Verify nose wheel shimmy damping capability.	Frequency
		Verify antiskid analysis and wheel tests.	Wheel rotation stopping distance
		Verify landing gear cycle performance	Time of operation, 10 seconds maximum
		Verify emergency gear extension capability.	Time
		Verify analysis and wind tunnel test results of flight control surface hinge moments and rates with loss of 1/3 hinge moment.	Hinge moment rate
		Verify TVC actuator load at touchdown at 80-percent landing gear design limit load	Load
	Structure (loads and response	Confirm calculated landing and taxi loads.	Sink speed landing shock acceleration and strain at selected points
	Structures (shock, vibration, aeroacoustics)	Confirm predicted landing and taxi transients	Transient accelerations and sink speed, landing speed and runway conditions
	Thermodynamics	(Continuation of Entry Requirement)	
	Crew systems	See Ascent	
	Electrical power generation	See Transition	
	Aerodynamics	Minimum service speed or stall warning onset whichever is the lower	Vehicle attitude, velocity and, resulting trajectory parameters
		Specification compliance	Vehicle performance and handling qualities, touchdown velocities, ground controllability, and landing distance data

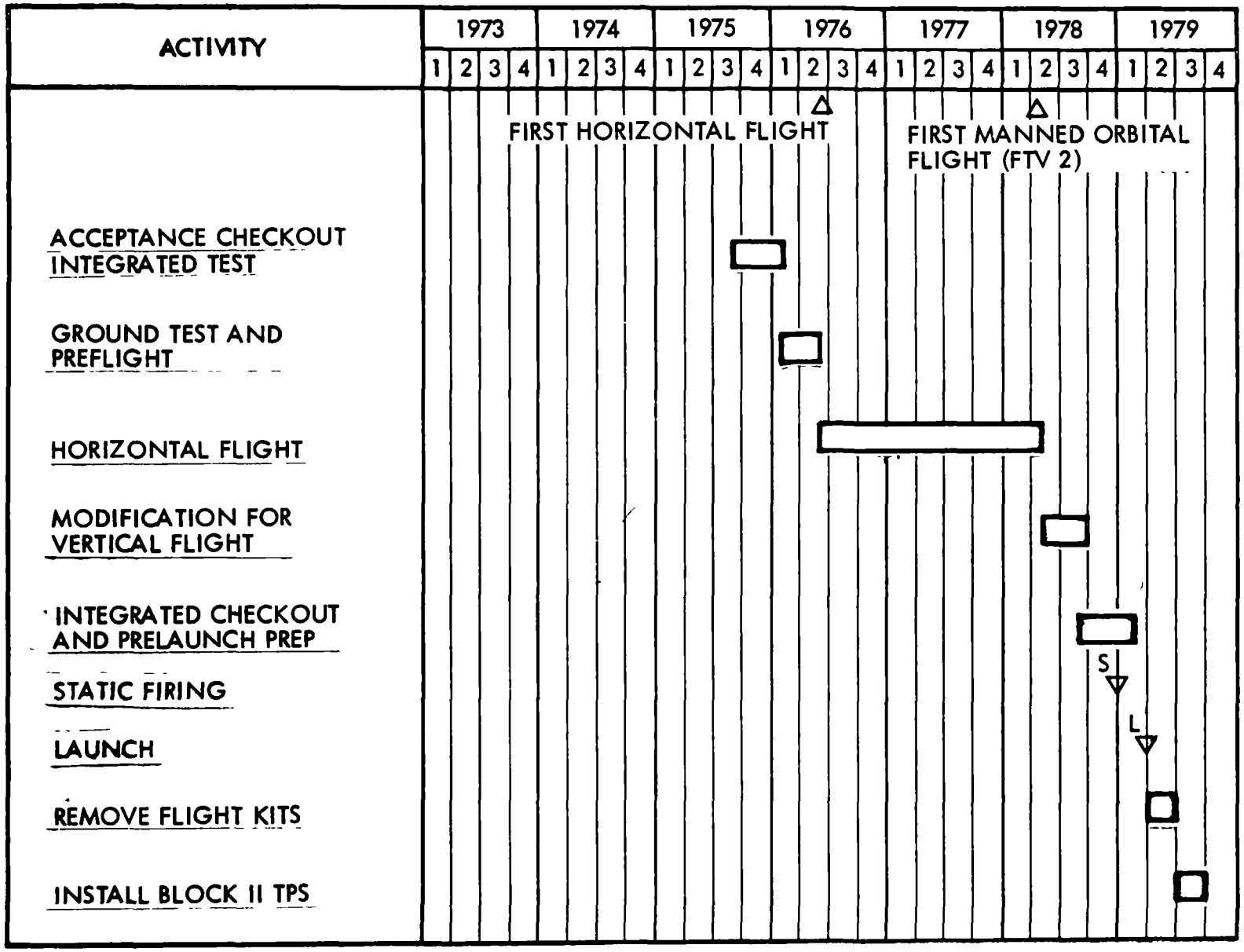


Figure 7-1. Orbiter 1 Schedule

and handling requirements in the approach and landing phase of the baseline orbiter configuration. The engine will be pylon-mounted and attached to the underside of the fuselage between the main landing gear and quick-disconnects will be provided inside the skin line to facilitate easy installation. One panel of reuseable exterior insulation will be removed and a fairing will cover the exposed area around the pylon. Engine controls from the cockpit to the pylon will be permanently installed.

Power Generation

The GH_2/GO_2 APU's for the baseline configuration will not be used for horizontal flight tests. Instead, power for electrical generation and hydraulics will be supplied by engine shaft power extraction from the four basic air-breathing engines. The hydraulic and electrical power generation units will be installed for horizontal flight tests and ferry flights but removed to save weight on operational missions.

Environmental Control System

The baseline configuration of the H_2 turbopump and heat exchanger to provide cooling will not be used during horizontal flight tests. Instead, a liquid-to-air heat exchanger installed outside the pressurized cabin compartment will be used. This unit is attached by removing a section of the skin and bolting the unit onto fittings provided for the unit.

Development Flight Instrumentation

The development flight instrumentation (DFI) and the communication subsystem, in conjunction with a ground telemetry station and real-time and postflight data reduction, will provide the tool through which the necessary visibility into subsystem and vehicle performance will be gained during flight test. Refer to Section 5 of this volume for DFI and communication subsystem descriptions and test plans.

The primary drivers used in defining the real-time downlink interface with the ground are as follows:

1. Crew and vehicle safety

2. Reduction of flight test hours through reduction of crew work load, data validity, verification that required maneuvers were executed, and the ability for real-time planning of alternate or additional tests

3. Early planning of postflight data processing and vehicle turnaround activities

4. Test data availability in event of vehicle loss

These drivers have resulted in the following application of the DFI and communication subsystem to the flight test phases.

1. It is expected that the DFI capability will include vibration measurements which will supplement the specialized nonflight instrumentation used for ground vibration testing.

2. Valuable preliminary data will be obtained from the initial flight to the test site. The DFI will be operational at that time; voice communication, telemetry, and tracking interfaces with flight test ground control will be exercised.

3. The use of the DFI during the horizontal flight test program will be for data acquisition in support of flight test analysis and reporting within the constraints of the flight test schedules. Data acquisition will consist of onboard recording and telemetering of multiple (currently approximately 4000) quasistatic measurements. The onboard data recorders will provide the capability for parameters whose bandwidth requirements are beyond those of the PCM telemetry. Analysis of data will be primarily handled by the ground system. Reduction and display of selected parameters for the ground flight controllers and subsystems specialists will occur in real time.

   Criteria for selection of data points for real-time display will be flight safety and the need for real-time assessment of test success. In general, the real-time reduction and display capability will augment decision making. Postflight analysis will consist of an initial "quick look" as required for planning of subsequent testing and a detailed analysis, probably at the contractors engineering facility.

   The expected flexibility of the DFI configuration will necessitate documentation that will enable real-time visibility of the DFI for test planning, data reduction, analysis, and reporting.

4. The role of the DFI and communications subsystems during manned orbital flight test will be essentially the same as during horizontal flight test. It is planned that MSFN and/or data relay satellites will be available and video data will enable real-time evaluation of complex operations associated with payload deployment and retraction and other operations in space.

Crew Escape Provisions

The crew escape capability is provided by ejection seats. The ejection seats are intended to provide emergency in-flight crew escape for the entire flight profile of the horizontal flight program and within specific regions of the flight profile for the vertical (orbital) flight test program.

7.1.2 Vehicle Ground Tests

This section contains the approach and rationale behind the acceptance requirements (Table 7-2) and the test flow logic diagram (Figure 7-2).

To a limited extent, acceptance checkout is affected by the configuration changes between orbiters. Although extensive horizontal flight testing is planned for only Orbiter 1 and no fully operational use of the main engines are required, an otherwise operational engine with structural features including gimballing and other electromechanical or hydraulic devices will be required. Accordingly, acceptance checkout in the final assembly area is not noticeably affected. In addition, Orbiters 1 and 2 utilize special instrumentation packages to verify development concepts and checkout of such instrumentation is required. Orbiter 3 is a fully operational vehicle and requires complete acceptance checkout.

The overall production checkout plan is formulated in accordance with the Shuttle Manufacturing Flow and Build Plan. The fuselage is divided into three major structural assemblies: forward, intermediate, and aft. Each section includes the installation of most major components and all tubing and wiring networks. The tubing installation requirements are verified by proof pressure, leak, and cleaning checks and the wiring installation requirements are verified by insulation, isolation, grounding, and shielding checks. During final assembly the fuselage sections are mated and the wings, stabilizers, crew compartment, and remaining major components are installed. The wiring and tubing interfaces are connected and checked out.

After final assembly, the operation of a fully integrated orbiter system is verified (i.e., checkout is performed on the combined structural, propulsion, avionics, vehicle support, and mechanical subsystems). Checkout requiring the use of hydrogen and oxygen is conducted at a site remote to the final assembly area and at a time coincident with preflight or launch testing. This saves additional costs for facilities to support these hazardous operations in the assembly building. Following integrated checkout, cabin leak rate, weight and balance, and crew personnel provision requirements are verified. A more detailed explanation of the approach - and - rationale behind final assembly and integrated subsystem checkout is presented in the following subsections.

Table 7-2. Acceptance Checkout Requirements

System Test No.	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
1-3	Electrical resistance at each interfacing connection is within specified limits							P
	Leakage at each interfacing tube joint is within specified limits.							P
4	1. Final rigging of aerodynamics surface positioning mechanisms.							
	a. Elevon							
	(1) Elevon null alignment error is within specified limits.							P
	(2) Elevon maximum angular displacement is within specified limits.							P
	b. Rudder							
	(1) Rudder null alignment error is within specified limits.							P
	(2) Rudder maximum angular displacement is within specified limits.							P
	c. Drag-brake							
	(1) Drag brake null alignment error is within specified limits							P
	(2) Drag brake maximum angular displacement position is within specified limits.							P
	2. Air-breathing engine deployment.							
	Engine deployment rigging and mechanical sequencing operations (release, actuation, latching, locking, and operational enabling signals) are within specified limits.							P
	3. Electrical power distribution and control.							
	a. Power conversion operations function within specified limits of frequency, waveform, ripple, and output regulation.							P

Table 7-2. Acceptance Checkout Requirements (Cont)

System Test No.	Certification Requirement	Certification Category: Analysis (1)	Computer/Model (2)	Component (3)	Assembly (4)	Subsystem (5)	Comb Subsystem (6)	Flight Vehicle (7)
4 (Cont)	b. Power control and protection devices function properly when specified signal inputs are applied (i.e., trip level, signal requirements, reset level, response time).							P
	c. Interlock mechanizations are functioning within specified limits.							P
	4. Electrical/mechanical power generation.							
	a. APU or H_2/O_2 turbine power unit. H_2/O_2 turbine transducer and logical elements are operating within specified limits under ambient conditions.							P
	b. H_2/O_2 fuel cell. Fuel cell transducer and logical elements are operating within specified limits under ambient conditions.							P
	c. Landing subsystems.							
	(1) Main gear							
	(a) Main gear stowed and deployed alignment positions are within specified limits.							P
	(b) Latching, locking, and sequencing operations function within specified limits							P
	(2) Nose gear. (Verification accomplished at nose fuselage level.)							P
	d Booster mating.							P
	e. Docking subsystem (rigged at supplier). (See integrated Checkout.)							P
	f Payload deployment.							
	(1) The cargo container stowed and deployed alignment positioning is within specified limits.							P
	(2) Latching, pulldown, locking, and sequencing operations function within specified limitations.							P

Table 7-2. Acceptance Checkout Requirements (Cont)

System Test No	Certification Requirement	Certification Category: Analysis (1)	Computer/Model (2)	Component (3)	Assembly (4)	Subsystem (5)	Comb. Subsystem (6)	Flight Vehicle (7)
5	1 Servo systems and control valves.							
	a. Aero surface							
	(1) Elevon polarity, maximum rate, position linearity and damping characteristics are within specified limits.							P
	(2) Rudder maximum rate, position linearity, and damping characteristics are within specified limits.							P
	(3) Drag brake maximum rate, position linearity, and damping characteristics are within specified limits							P
	b. Air-breathing engine.							
	(1) Air-breathing jet engine fuel control valve linearity characteristics are within specified limits.							P
	c. Landing gear.							
	(1) Main landing gear and door hydraulic control valve responses to operating signals are within specified limits							P
	(2) Nose gear and door hydraulic control valve and actuator responses to operating signals are within specified limits.							P
	d. Payload deployment. Payload deployment responses to operating signals are within specified limits							P
	e. Fuel cell. Fuel cell reactant control valve responses to operating signals are within specified limits.							P
	f. Turbine power. H_2/O_2 turbine auxiliary power units reactant control valve responses to operating signals are within specified limits.							P

Table 7-2. Acceptance Checkout Requirements (Cont)

System Test No.	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
5 (Cont)	g. Docking mechanism The docking mechanism pulldown responses to operating signals are within specified limits							P
	1. Integrated hydraulic system.							
	(1) The hydraulic servo control loops function within specified operating tolerance. The H_2/O_2 turbine auxiliary power units will not be included.							P
	(2) The hydraulic reservoir and GN_2 pressurization system operate within specified limits of pressure and flow rate							P
	(3) The hydraulic fluid cooling equipment function within specified limits of flow rate and pressure.							P
	(4) The performance of the auxiliary hydraulic power and fluid conditioning pump is operating within specified limits when operating as part of a fully integrated hydraulic system.							P
	3. Integrated thermal control.							
	a The fully integrated thermal control subsystem functions as specified							P
	b. Valves associated with space radiator door position, function to control the flow of cooling fluid to the space radiator when open, or the sublimators when closed.							P
	c. The flow rate and pressure for each cooling loop operate within specified limits.							P
	d. Pump efficiency is within specified limits.							P
	4. Sextant optics. The sextant optics referenced alignment is within the specified limits.							P
	5 IMU hexad.							
	a. Alignment is within specified limits							P
	b. Outputs are within specified limits.							P

Table 7-2. Acceptance Checkout Requirements (Cont)

System Test No.	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
5 (Cont)	6. Docking. The docking hatch mechanisms function within specified limits of leakage, depressurization and pressurization control, opening and closing torque, lighting, window refraction, and that associated electro optical laser, and television support equipment function within specified limits							P
	7. Programmed/automatic operations.							P
	a. Air-breathing engine. Air-breathing engine programmed deployment characteristics are within specified limits of deployment time and event sequencing.							P
	b. Electrical power distribution and control. Automatic emergency electrical power transfer operations function as specified.							P
	8. Data control and management.							
	a. The computer memory complexes function within specified limits.							P
	b The operation of the ACT units are within specified limits.							P
	c. The operation of the data management computer is within specified limits							P
	d. Data bus control operations functions within specified limits.							P
	e. The mass memory control unit is functioning within specified limits.							P
	f. Air data sensors are operating within specified limits.							P
	9. Cryogenic storage. The cryogenic storage and distribution system's control and sensing element for the environmental system and the fuel cells are functioning within specified limits							P

Table 7-2. Acceptance Checkout Requirements (Cont)

System Test No.	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
5 (Cont)	10. Displays and controls.							
	a. The caution and warning display is operating within specified limits							P
	b. The multiformat CRT display, the alpha-numeric display, and buffer are operating within specified limits							P
	11. Electromagnetic interference. The operation of the fully integrated electrical-electronic system is within specified electromagnetic interference levels.							P
	12. Communications. The operation of the antenna selectors, VHF/AM transceivers, digital ranging generator, updata link equipment VHF/FM transceivers, S-band power amplifiers, unified S-band equipment,. signal processor, DME transponder, VOR receivers, ATC transponders, radar altimeters, ICS and marker beacon receivers are functioning within specified limits.							P
	13. Software. The GN&C, communication, data control and management, onboard checkout (i. e., failure prediction caution and warning), integrated displays and controls, and power distribution and control software programs are mechanized properly.							P
	14. Cabin leak rate checkout. The cabin leak rate is within specified limits of pressure decay.							P
	15. Weight-and-balance and crew systems fit and functional. The orbiter weight and balance characteristics are within specified limits							
6	Crew compartment leakage rates are within specified limits							P
7	Flight personnel provisions are within acceptable standards.							P

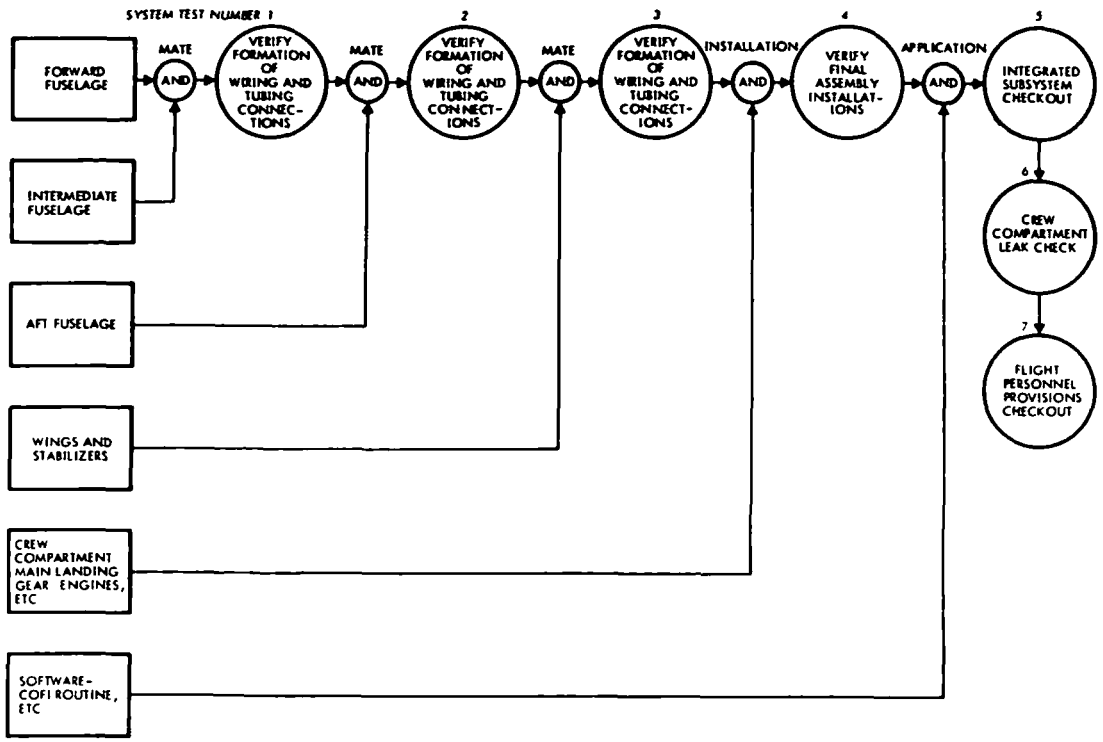


Figure 7-2. Test Flow Logic Diagram (Orbiter Final Assembly and Integrated Subsystem Acceptance Checkout)

Final Assembly Checkout

Checkout procedures to be conducted during final assembly are described in the following paragraphs.

Aerodynamic Surfaces. To permit production flexibility, actuator rigging adjustments are accomplished at both the structural subassembly level and at final assembly. The checkout verifies that the actuator null is properly aligned and that maximum required angular displacements are within working ranges of the actuator. These rigging adjustments are required for 11 elevons, rudder, and speed brake actuators Since the amplifiers associated with the actuator control loops are included as part of the GN&C subsystem, this checkout is described under Integrated Subsystem Checkout.

Air Breathing Engine Deployment. Checkout includes verification of rigging performed during final assembly. Hydraulic power, hinges, valves, latches and locks are included. Valve drivers and manual or automatic controls are verified during integrated subsystem checkout.

Environmental Control and Life Support. At final assembly, the crew compartment is attached to the forward fuselage assembly and service cables and tubing are attached. Most components have been installed in the crew

compartment at the subassembly level. These components also are checked out at the subassembly level. Production flexibility will permit component installation and checkout at the final assembly level. Production checkout at final assembly, however, will consist mainly of verifying that electrical connectors are mated and the tubing connections are properly joined.

Electrical Power Distribution. Performance of the ac and dc bus networks with associated transformer rectifiers, contactors, and controllers for specified operation is verified. Specified frequency, wave form, ripple voltage, and voltage regulation characteristics are checked. Verification before integrated subsystem checkout permits efficient and safe power application to subsystem components.

Electromechanical Power Generation. Operation of the fully operative H_2/O_2 auxiliary power units will be verified during post-checkout operations prior to first flight. The ambient state of electromechanical input-output devices is verified.

Fuel Cell Power Generation. A fully operative fuel cell component will not be verified in this phase of the production effort. The ambient state of input-output controlling devices will be verified, however.

Landing Subsystems. Verification of nose landing gear rigging is accomplished at the forward fuselage subassembly level. Accordingly, checkout is not required at final assembly. However, the main gear is installed and rigged in final assembly. Adjustments of actuator linkages, locks, and latches are verified.

Nose Gear Steering and Main Gear Braking. Components for steering and braking are integral parts of the nose and main gear assemblies. Nose gear steering electrical and electromechanical input-output devices is checked at the forward fuselage subassembly level and the braking input-output devices will be checked at the final assembly level since the nose gear is installed at the subassembly level and the main gear is installed at the final assembly level.

Emergency Landing Gear Operations. Performance of emergency deployment, braking, and steering mechanizations is verified. The performance of dump valves, accumulators, emergency switches, etc., will be verified.

Booster Mating. The booster is mated to the orbiter by means of an explosive bolt arrangement in which all active control elements are part of the booster systems Functional verification of orbiter-booster data and voice umbilical separation will be performed.

Docking System Rigging of the docking mechanism is accomplished by the docking mechanism supplier. Accordingly, no final assembly rigging checkout is required. Checkout of tubing and electrical cable connections to the active docking mechanism is accomplished at the forward fuselage subassembly level Crew compartment control capability is verified during integrated subsystem checkout The operational requirements of docking visual and electronic aids also are verified during integrated subsystem checkout

Payload Deployment Assembly of the cargo doors and crew compartment is accomplished at final assembly. The access tunnel between the crew and cargo structures is included Actuator linkages, locks, and latches are adjusted and verified for deployment operations

Air-Breathing Engines All interlocking and protective functional mechanizations and adjustments are verified Operation of caution and warning mechanizations are included under integrated subsystem checkout

Integrated Subsystem Checkout

The vehicle-level integrated checkout and acceptance test will be performed after final installation of the systems into the orbiter vehicle. These tests will assure the system meets the requirements of the applicable system design drawings and specifications Development of the integrated final system checkout and acceptance procedure will be based upon the following ground rules.

1 Maximum utilization will be made of the checkout and fault isolation (COFI) for evaluating the performance of any given system Supplemental software will be used to permit approximation of dynamic operation through the use of selected synthetic stimuli.

2 Maximum use will be made of the onboard checkout equipment but support equipment will be used to supplement it during production checkout to alleviate cockpit congestion during this period.

3 Software routines for the integrated avionics system (IAS) and other systems will be developed and validated prior to use for factory test

4. System electromagnetic compatibility will be evaluated by performance checks during integrated checkout. Electromagnetic emission or susceptibility will have been determined previously at the subassembly (black box) level

5. Redundant circuits and controls will be switched in and out to assure each of the redundant circuits perform properly.

The integrated system test will, to the highest degree practical, simulate actual horizontal takeoff, subsonic flight, approach, and landing functions and sequences to assure that all subsystems will perform properly in conjunction with all other subsystems.

Integrated subsystem checkout verifies the capability of the data control and management subsystem to function with other subsystems and manage vehicle operations during flight and ground modes. Typically, checkout verifies that automatic and manual flight controls function properly when more than one subsystem is considered (i.e., data control and management; displays and controls; guidance, navigation and control, etc.). Other typical checkouts include launch sequences, docking, etc Elements of subsystems which require integrated checkout are described in the following paragraphs

Servo Loops and Control Valves. To assure that aerodynamic surface power systems have been properly integrated with manual and automatic control systems and that data management and control functions have been properly applied, limited servo response testing is performed. Checkout of the trim system and control loop is made by determining the surface displacement rates, measuring actuator angular displacement for input signals of varying amplitude, verifying proper polarity responses, and verifying that there are no excessive oscillation or overshoot tendencies. This checkout is applied to the elevon, rudder, speed-brake, thrust vector, and other proportional control systems. The response time, fuel oxidizer sequencing, and polarity of reactant control valve operations are verified to assure integrated subsystem functional compatibility.

Landing Gear. Landing gear response to automatic and manual controls is verified to assure integrated subsystem function compatibility. The landing gear retraction time is a critical factor in the orbiter emergency go around capability when one engine is out. Provisions are made for landing gear retraction rate verification.

Nose Wheel Steering and Main Gear Braking. Functional checkout of steering and braking operations is performed at the airfield coincident with taxi tests However, a dry checkout of automatic and manual controls is performed by verifying the electrical performance of control and monitoring signals

Software. The performance of the computer program required for the operation of a fully integrated avionic subsystem group and other affected orbiter elements are verified. Checkout and fault isolations are verified.

Avionics Subsystems Compatibility Checkout demonstrates that the fully integrated avionics subsystem group functions in concert with other elements The avionics subsystem group includes guidance navigation and control, data control and management, displays and controls, electrical power distribution and control, and communications Other orbiter elements include hydraulic and pneumatic valves, instrumentation, sensors, cooling (not part of electrical power and control subsystem), electrical and mechanical power generation equipment, and various electrical switches and controls.

Environmental Control and Life Support Subsystem. The performance of a fully integrated ECLSS is verified. Elements of the ECLSS include cabin environmental control equipment, waste management facilities and equipment, and water and food facilities and equipment. Other interfacing subsystems include control and displays, data management and control, and guidance, navigation and control.

Communications. The performance of a fully integrated communications subsystem is verified. Elements of the communications subsystem include antennas, antenna selectors, updata link equipment, VHF/FM transceivers, S-band power amplifiers, unified S-band equipment, signal processors, UHF ATC, ATC transponders, radar altimeters, and precision ranging interrogator. Other interfacing subsystems include displays and controls, and data management and control.

Weight and Balance and Crew Systems Fit and Function. The orbiter is weighed to determine its weight and balance characteristics. Also, the performance of crew fit and functional equipment is verified

Cabin Leak Rate Checkout. Before customer acceptance, the crew-passenger cabin hatches are closed and the cabin pressurized and its leak rate measured to verify that integrity of cabin seals.

Special Instrumentation Before initiating flight tests, the functional operation of special instrumentation packages is verified. (This checkout is limited to Orbiters 1 and 2.)

Payload Deployment. Operation of deployment actuators, latches, locks, and controlling valves is verified to assure a fully operational and integrated orbiter subsystem.

Power Generation. The operation of the fuel cell and APU valve transducers and logical elements are combined with the operation of the data management and control subsystem and the electrical power distribution and control subsystem to verify combined subsystem functional compatibility. Checkout using gaseous reactants is accomplished during post checkout operations at a remote site.

Hydraulic Power Subsystem. The hydraulic power subsystem includes four separate distribution networks, each arranged to include a hydraulic pump, fluid reservoir and pneumatic pressurizing system, distribution lines, check valves, filters, and power elements such as actuators. The pump is powered by an H_2/O_2 APU which also drives an ac generator. The integrated checkout of this entire subsystem is accomplished during post-checkout operations The hazards involved in operating the APU require that this checkout be performed at a site remote to the final assembly area

Rocket Propulsion and Major Structural Subsystems. The main LH_2 and LO_2 tanks are part of the structures subsystem. The other tanks and all distribution networks are part of the engine systems they service. A fully integrated and active checkout of these systems (i.e., main, orbit maneuvering, and attitude control) is performed coincident with preflight or prelaunch testing. However, the operation of electrical "input-output" devices when combined with the operation of the data control and management, controls and displays, and other subsystems is verified during integrated subsystem checkout

Air-Breathing Engine. Checkout performance of the fully integrated ABE equipment is conducted at a remote site. However, the dry performance of electrical and electromechanical input-output devices will be verified during integrated test.

Controls and Displays. The functional operation of a fully integrated displays and controls subsystem is verified. Elements of the displays and controls subsystem include a multiformat CRT display, an alphanumeric display, caution and warning indications, manual flight controls, multifunction controls, and necessary sensors. Other subsystems in the integrated checkout included guidance navigation and control, data control and management, communications, hydraulic power and electrical power distribution and control.

Post-Checkout Operations and Preflight Activities

Post-checkout operations (PCO) following integrated activities include transport by barge to the U. S. Naval Air Station, Point Mugu, California, where final preparations for first flight will be performed. Included in the PCO phase are those tests to be performed at a site suitable for "hot fire" of APU's, ABES, and fuel cells and ABES fuel system calibration

Requirements

Requirements for PCO and preflight testing at the final assembly site, the Naval Air Station—Point Mugu and EAFB are given in Table 7-3 A description of the barging operation is in the Facility Utilization and Manufacturing Plan.

Approach and Rationale

The general plan for the tests to be accomplished at Seal Beach, NAS, Point Mugu, or at EAFB is as follows·

1. Vehicle horizontal ground vibration tests will be performed to validate that the natural frequencies of the structure are as predicted and to determine vibration modes and damping characteristics. (Seal Beach)
2. Weight and balance will be determined, and ABES fuel system will be calibrated in the horizontal and nose-up and nose-down attitudes (Seal Beach)
3 Landing gear and aerocontrol surfaces will be proof loaded to approximately 80 percent of design value (Seal Beach)
4 Air-breathing engines will be test run and ABES electrical and power generation performance will be verified. (Point Mugu)
5. Taxi tests will verify final readiness for flight and will establish suitability of engine response, vehicle response to power, nose wheel steering, landing gear stability, braking effectiveness, flight control response, nosewheel liftoff, displays and controls, and cockpit layout. (Point Mugu)
6. The power generation subsystem APU and fuel cells will be operated using the ground supplied gaseous reactants. (EAFB)

Figure 7-3 shows the schedule for Orbiter 1 PCO and preflight activities prior to the start of the horizontal flight test program

Table 7-3. Preflight Ground Certification Requirements

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
* 1. Dynamic model response of vehicle							P
2. Weight and balance							P
3. Proof loading of landing gear, flight controls, and other hydraulic systems							P
* 4. Crew emergency and normal egress subsystems							P
5. Antenna system performance							P
6. Power generation and propulsion systems quantity gauging subsystems							P
* 7. Ability to load and offload PRSD and ABES tanks							P
* 8. Ability to load and offload ECLSS water and nitrogen systems.							P
* 9. Ability to service ECLSS sublimators and humidity control heat exchangers							P
10. Ability to start up and shut down fuel cells							P
11. Ability to start up and shut down APU's.							P
12. Ability to start up, control, and shut down ABES.							P
*13. Compatibility between airborne electrical and hydraulic power sources and other vehicle subsystems							P
* 14. Verification that ECLSS provides specified atmospheric environmental control for personnel and equipment using H_2 heat exchanger for heat sink							P
15. Ability of DCM and its software to manage airborne power sources and vehicle subsystems							P
16. Flight test instrumentation while using airborne power							P
17. EMI/EMC during APU, fuel cell and ABES operation.							P
18. Adequacy of support equipment							P

* Developmental issue that would not apply to FTV 2 and subsequent

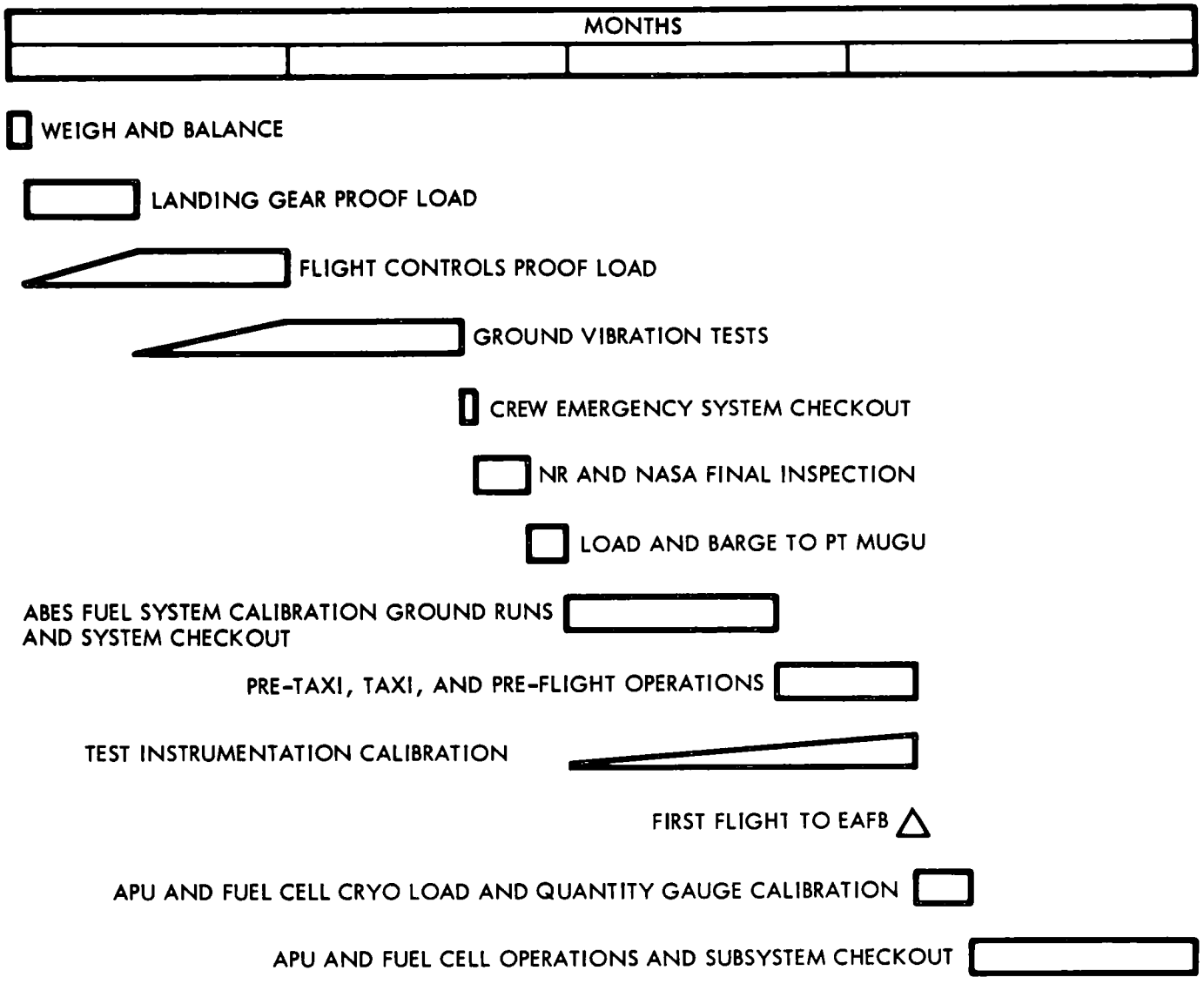


Figure 7-3. Orbiter Vehicle 1 Post-Checkout and Preflight Ground Test Schedule

7.1.3 Horizontal Flight Test

Requirements

Orbiter test requirements are derived from verification requirements delineated in Section 4.0 of the Orbiter End Item Specification. The major flight test requirements are itemized in Table 7-4.

Approach and Rationale

The horizontal flight test plan is to assure that the orbiter operates satisfactorily in the subsonic flight portion of the mission. Tests will include takeoff, climb, cruise, descent, and landing within the performance envelope of an orbiter in the basic configuration for mission termination and for ferry flight.

The test outline selected is a 180-hour flight program based on a qualitative analysis of orbiter flight test requirements. Experience gained on NASA and military test programs, including the X-15, XB-70, and A3J has been applied for aircraft testing. Apollo CSM and Saturn S-II experience in the areas of spacecraft testing, parallel test, extensive use of real-time instrumentation, and troubleshooting was also used.

The horizontal subsonic flight test phase is designed to accomplish the following objectives:

1. Demonstrate an acceptable level of airworthiness and flight safety.
2. Accomplish inflight development and calibration of subsystems.
3. Demonstrate specified levels of vehicle and subsystem performance.
4. Support the vertical flight test program and optimize cruise, approach and landing, and ferry operations.
5. Develop/verify flight operations procedures.

The following assumptions and ground rules were used in the definition of the Phase C/D horizontal flight test program:

1. The CEI Design Specification will be the basis for all subsonic flight test requirements specified in the detail flight test plans prepared during Phase C/D.
2. Inflight data, measured and recorded during subsonic horizontal flight tests, will be used for verification of subsystem flight worthiness.

Table 7-4. Subsonic Flight Test Detail Requirements

	Certification Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
1	Airspeed calibration							P
2	Evaluation and optimization of climb, cruise, and descent performance							P
3	Manual approach and landing							P
4	Automatic approach and landing							P
5	Takeoff and landing characteristics at limits of the range of weights and centers of gravity for operational and ferry flights							P
6	Takeoff control effectiveness							
7	Aeroelasticity, vibration, and flutter characteristics							P
8	Handling characteristics throughout the service flight envelope							P
9	Longitudinal and lateral-directional stability and control a Manual control mode b Automatic control mode c Powered flight d Glide flight e Selected failures							P
10	Trim capability							P
11	Demonstration of orbiter structural integrity							P
12	Demonstration of approach and landing under limited operational weather conditions.							P
13	Ability of DCM and flight software to manage vehicle subsystems							P
14	In-flight performance and stability of electrical and hydraulic power generation system							P
15	In-flight performance of ECLSS using hydrogen heat exchangers for heat sink							P
16	In-flight performance of communications systems with emphasis on S-band capability							P
17	Satisfactory operation of fuel cells and APU's simultaneously							P
18	In-flight performance of hydraulic/controls subsystem							P

Table 7-4. Subsonic Flight Test Detail Requirements (Cont)

Certification Requirement	Certification Category						
	Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
	1	2	3	4	5	6	7
19 In-flight inertial navigation system capability within the limitations of the orbiter flight duration and range							P
20. ABES engine-out, and restart characteristics							P
21 In-flight performance of reactant propellant tanking, distribution, and gauging systems							P
22. In-flight performance and fuel consumption of ABES under various flight modes							P
23 D&C, crew cockpit visibility, and general illumination are adequate for safe control during all modes of flight							P
24 Stall warning onset or minimum service speed, whichever is the lower							P
25 In-flight performance of electrical power distribution and control systems							P
26 Stabilization and control characteristics — one engine out							P
27 Precision ranging system capability							P
28 Satisfactory operation of wheel brakes and antiskid							P
29 Satisfactory operation of speed brake							P
30 Satisfactory operation of nose wheel steering							P
31 Satisfactory operation of drag chute							P
32 Adequacy of flight personnel provisions							P
33 Buffet onset boundary							P
34 Demonstration of landing gear to 80-percent limit design load							P

3 Data acquisition and processing will use telemetry data link to the ground station for near real-time data processing, computation, and presentation.

4 Limited subsystem development testing will be accomplished.

5 A limited ABES airstart envelope will be determined

6 Specific FAR and military specification requirements will be used as guidelines for demonstrating airworthiness and safety

7. Limited retest following redesign for problem solution will be accomplished

8. The service flight envelope, as outlined in MIL Specification 8785, will be determined.

9. Nominal takeoff and landing performance data will be obtained

The following typical airplane flight test operations are excluded because they are inappropriate to the orbiter horizontal flight program, or the requirements for such operations have not yet been defined:

1 Expansion of the flight envelope into the transonic/supersonic flight regime

2. Flights specifically for customer demonstration or customer's flight crew familiarization

3 Maintenance demonstrations; however, timeline data will be obtained during the flight test program

4 Spin entry and recovery evaluation

The horizontal flight test program for Orbiter 1 was defined based upon these assumptions and ground rules Figures 7-4 through 7-10 provide a breakdown of the horizontal flight test program which is considered an absolute minimum to assure safe, satisfactory, orbiter operations during the pertinent mission phases. These figures are intended to provide further definition of the flight testing activities and are directly relatable to Table 7-4.

7.1.4 Vertical Flight Test

After satisfactory completion of the horizontal flight test program at EAFB, Orbiter 1 will be ferried to KSC. Modifications necessary to support

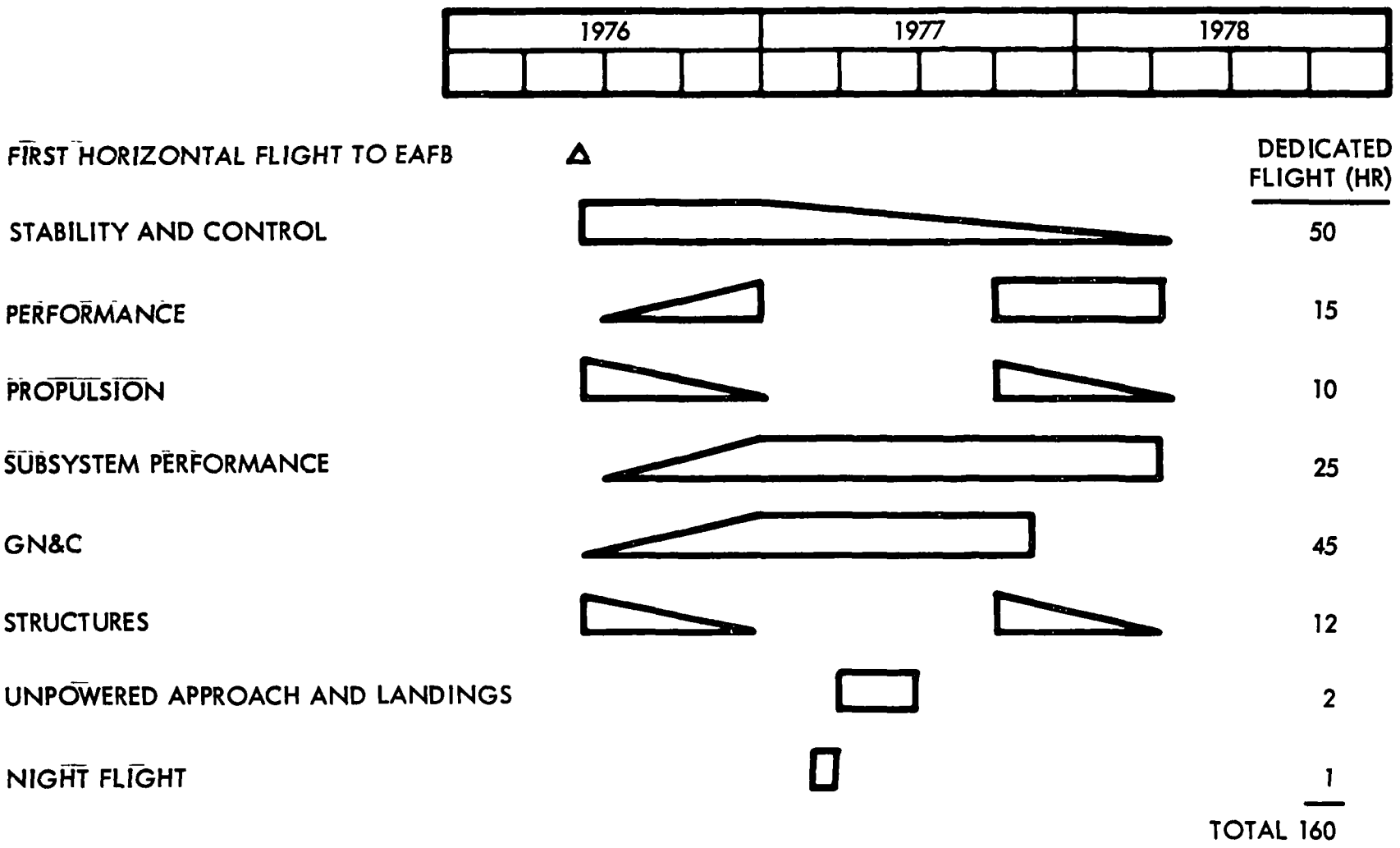


Figure 7-4. Orbiter Vehicle/Horizontal Flight Test Schedule

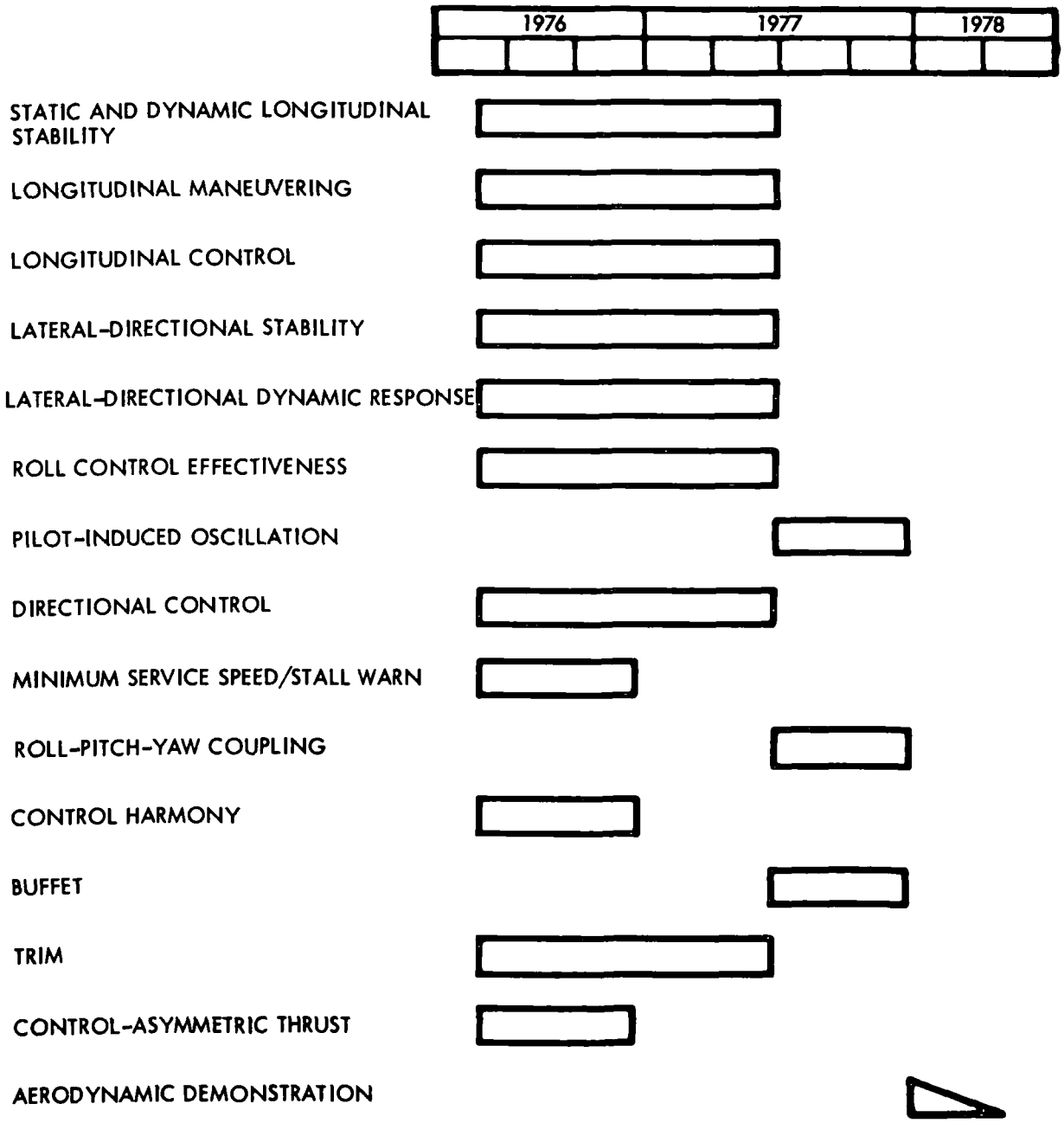


Figure 7-5. Orbiter Vehicle 1 Flight Test Schedule, Stability and Control and Handling

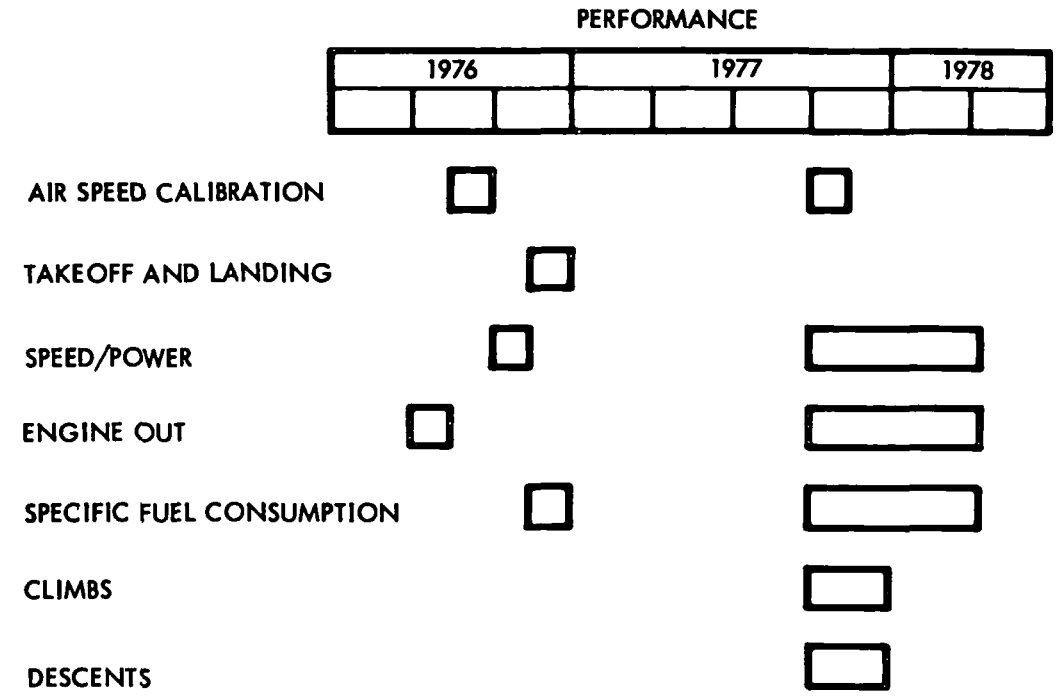


Figure 7-6. Orbiter Vehicle 1 Flight Test Schedule, Performance

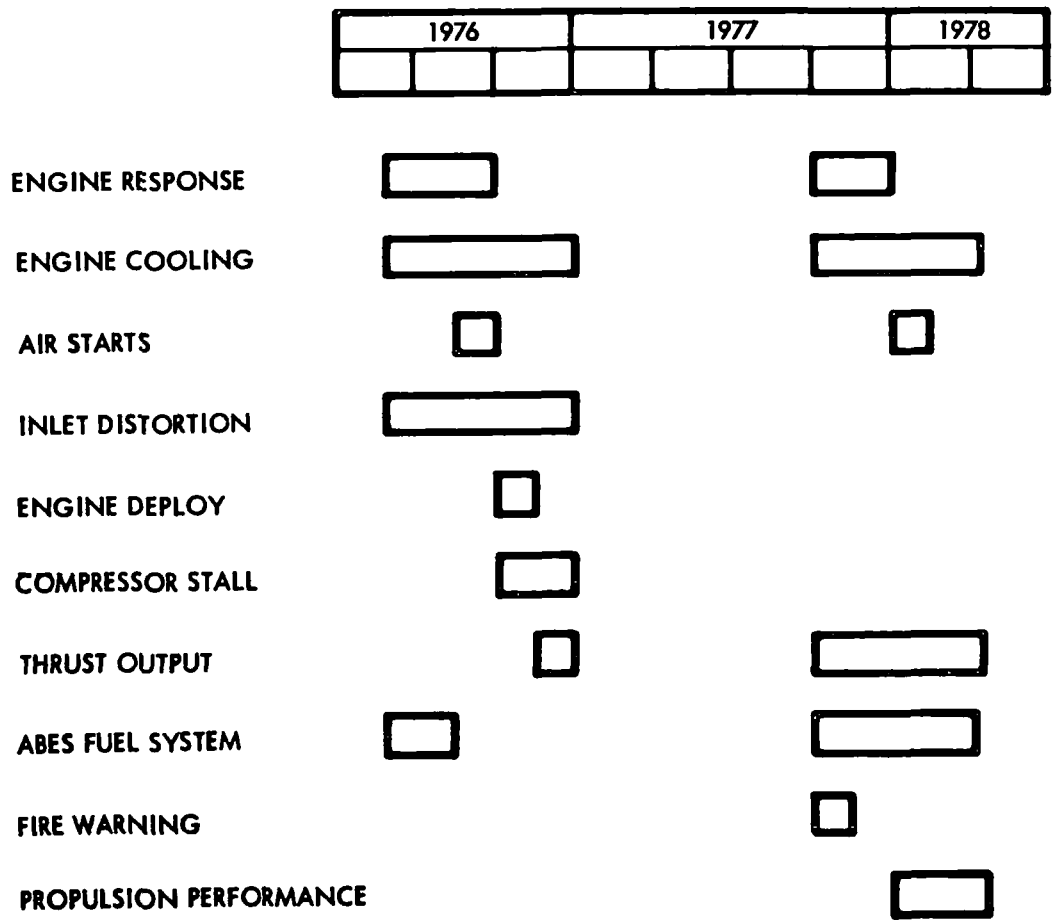


Figure 7-7. Orbiter Vehicle Flight Test Schedule, ABES Propulsion

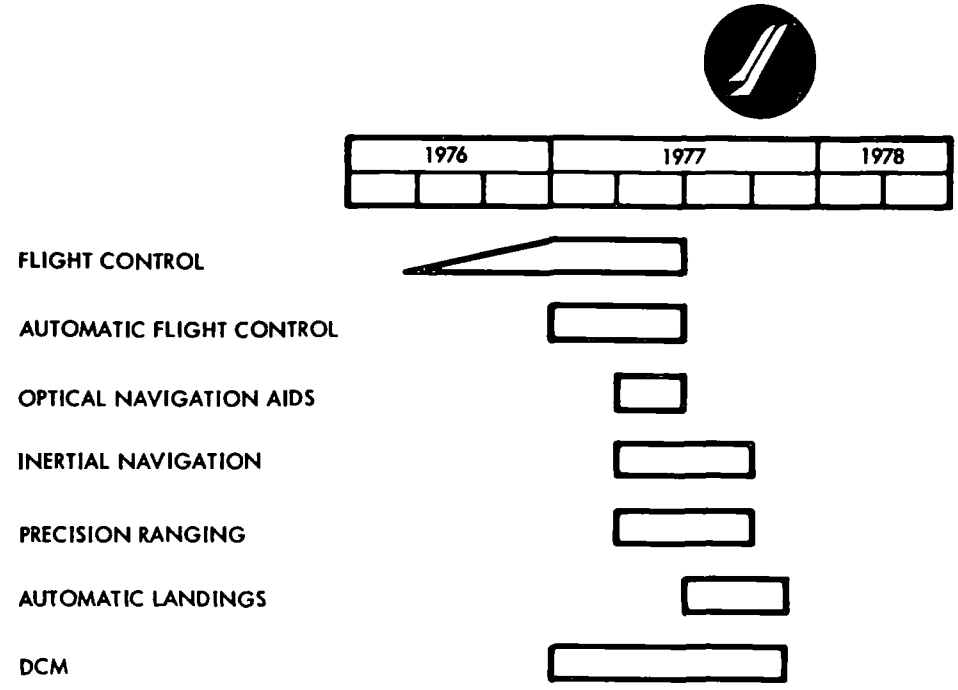


Figure 7-8. Orbiter Vehicle 1 Flight Test Schedule, GN&C

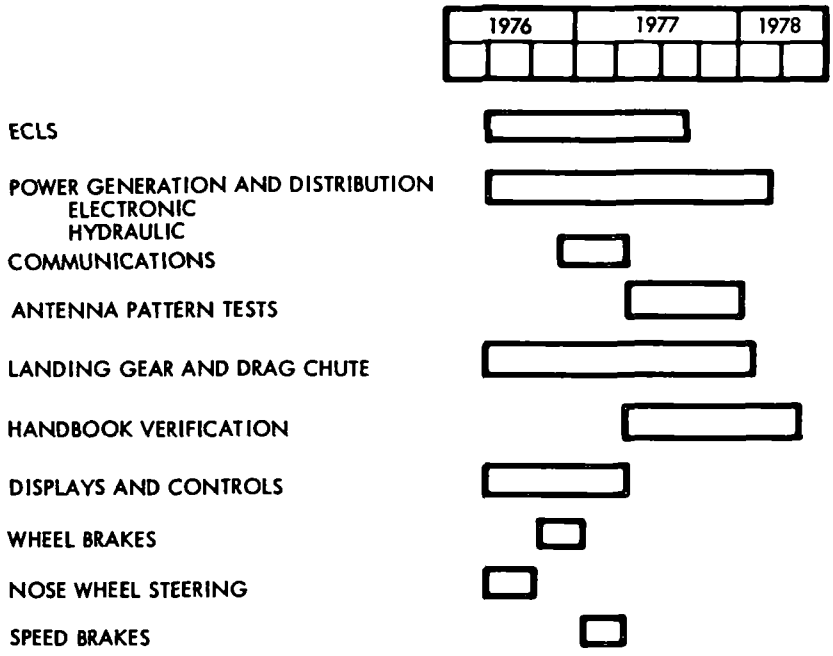


Figure 7-9. Orbiter Vehicle 1 Flight Test Schedule, Subsystem Performance

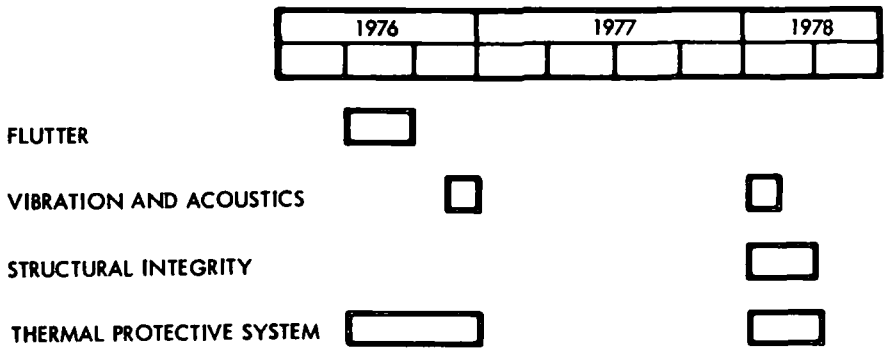


Figure 7-10. Orbiter Vehicle 1 Flight Test Schedule, Structure

vertical mated flight will be made, including installation of the MPS rocket engines. Identification of the test requirements, as well as a description of the prelaunch and launch operations, is provided in Volume I and Table 7-1.

7.2 ORBITER VEHICLE 2

Orbiter 2 is scheduled for the first space flights. It will be fully configured for flight and space test with DFI installed. It is also planned to supplement the horizontal subsonic flight tests of Orbiter 1 for this vehicle. Approximately 25 hours of subsonic flight testing is planned prior to the vehicle use in the first manned orbital flight.

Orbiter 2 will follow the same general flow sequence as Vehicle 1; i.e., after integrated checkout, ground tests will be accomplished. These tests will be an abbreviated version of those tests performed on Orbiter 1 The vehicle will be prepared and shipped to Point Mugu and subsequently ferried to EAFB. The flight tests conducted at EAFB will include vehicle airworthiness and will demonstrate readiness for the ferry flight to KSC. The EAFB site was chosen for these tests because of the added safety provided by the lake bed for the first flights and because the test range and the entire support facility are established and operating in support of Orbiter 1 at this phase of the program. Orbiter 2 activities at KSC, including checkout, integrated test, static firing, prelaunch and launch operations, are described in Volume I. Figure 7-11 provides an overall flow sequence for Orbiter 2.

7.3 ORBITER VEHICLE 3 AND SUBSEQUENT VEHICLES

Orbiters 3 and subsequent are dedicated to support of the operational missions. As a result, flight test kits including the development flight instrumentation and the crew escape ejection seats will not be incorporated. Each vehicle will be subjected to a series of ground tests to ensure satisfactory operation. The vehicles will be barged from Seal Beach to Point Mugu where a preflight checkout will be performed prior to first flight and landing at EAFB. Sufficient testing will be accomplished at EAFB to ensure readiness for the ferry flights to KSC.

Each vehicle will undergo a flight-readiness static firing at KSC. The general sequence of operations is provided in Volume 1. A description of the vehicle preflight and postflight operations is included in the Operations Plan.

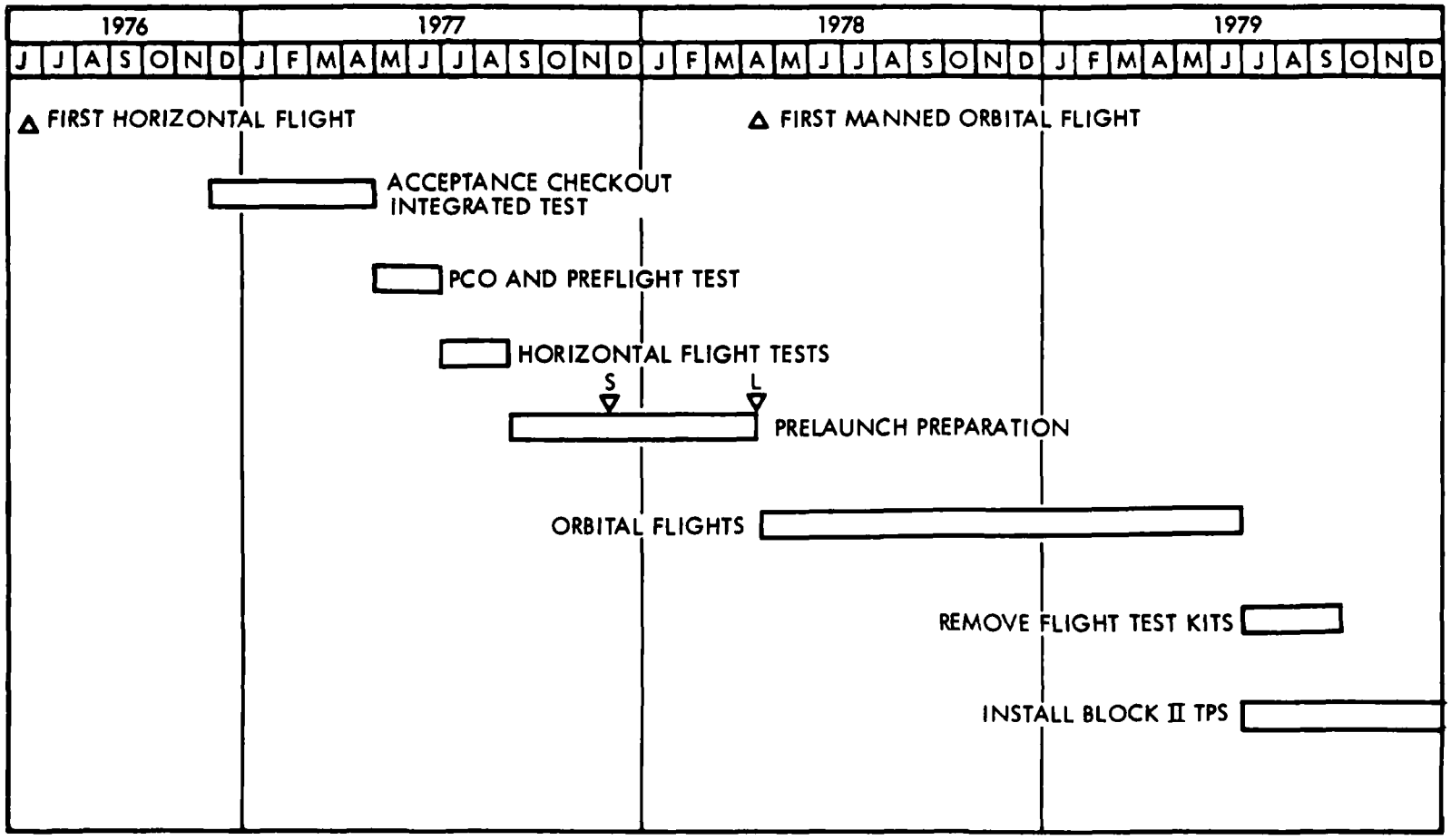


Figure 7-11. Orbiter 2 Flow Schedule

7.4 SUPPORT REQUIREMENTS

Presented in this section are the facility and ground equipment requirements necessary to support the vehicle acceptance, preship ground tests, preflight checkout at Point Mugu, and horizontal flight testing at EAFB. Requirements to support the standard ferry operations and prelaunch and launch operations at KSC are provided in the Operations Plan. The description of test support facilities is furnished in the Facility Utilization and Manufacturing Plan. Unique test support requirements at KSC are identified in Volume I of this plan.

7.4.1 Vehicle Acceptance

Facilities

The vehicle acceptance testing will take place at the manufacturing final assembly site. A description of the facility is provided in the Facility Utilization and Manufacturing Plan.

Support Equipment

In addition to vehicle access workstands and handling equipment, the following is a list of support equipment necessary for vehicle checkout.

Vehicle electrical simulation unit

He-GN_2 regulator console

Hydrocarbon analyzer

Moisture monitor

Mass spectrometer

Hydro fill and drain

Vacuum cart

Solvent flush panel

Control surface protractor

Hydraulic powercart

Electrical ground power and distribution

Multi-switching and measurement unit

Auto circuit analyzer

Flo-meter-gas

Flo-meter-fluid

Solvent flush cart

Rocket engine test kit

Keyboard word generator

Optical align set

Electrical cable set

RF switching console

VSWR measurement unit

Precision dc power supply

Data bus act unit

Channel chart rec

Caution and warning checkout unit

Binary to octal display

Signal select panel

Digital voltohmeter

Antenna checkout group

RF transmission line set

RF system checkout unit

Modulation checkout unit

VFH checkout unit

S-band antenna checkout

Bus monitoring record

Bus monitoring unit

Variable req. and volt eq.

Variable electrical load

Fuel cell sensor simulator

Radiator protect cover

Fluid distribution unit

Coolant service units

Rocket engine align set

Engine response recorder

Variable hydraulic load bank

Coolant flow cont.

Ground cooling cart

AC hydraulic jacks

GN_2 dry/purge cart

7.4.2 Preship Ground Test

In addition to the supporting shops and laboratories at the final assembly site, equipment requirements for the post-integrated ground tests and preparation for shipment are as follows:

Landing gear proof load equipment

Aerodynamic surface proof load equipment

Vibration and flutter test equipment

Air bays

On-line computer support

Power density spectral analyzers

Low pressure, high volume blower (mobile)

GN_2 purge cart

Personnel off-loading stairs and platform (mobile)

Jet fuel defueler

Work stands

Tow tractor and towbars

Jacks, tripod

Jacks, alligator

Hydraulic test stands

Empennage work stands

Fuselage work stands

Engine work stands

Cabin access stairs

Load bar

Generator test stand

Pneumatic test stand

Hydraulic bench test equipment

GN_2 service cart

Jet engine starting carts

Electrical test set (mobile)

Miscellaneous slings and dunnage for use with facility cranes

Motor generator

7.4.3 Preflight Checkout (Point Mugu)

1. Facilities
   a. Hangar space for maintenance and repair
   b. Office space
   c. Taxi strip
   d. Supporting shops and laboratories
      (1) Sheet metal and machine shop
      (2) ABES shop
      (3) Avionics and electronics laboratory
      (4) Standards calibration laboratory
      (5) Tubing shop
      (6) Fluids laboratory
      (7) Safing area
      (8) Propellant storage and transfer
2. Support equipment
   a. Mobile low pressure, high-volume blower
   b. GN_2 purge, service cart work stands
   c. Tower tractor and two bars
   d. Jacks, tripod (100-ton capacity)
   e. Hydraulic test stands (4000 psi, 200-GPM capacity)
   f. Engine removal stands

g. Jet and rocket engine transporters

h. Dollies

i. Generator test stand

j. Pneumatic test stand

k. Jet engine test stand with silencer

l. Blast deflectors for ground engine runup

m. Jet starting carts

n. Electrical test set

o. X-ray equipment

p. Motor generator

7.4.4 Horizontal Flight Test (EAFB)

The horizontal flight test facilities requirements are presented in Table 7-5. Table 7-6 lists the range support service requirements.

Table 7-5. Horizontal Flight Test Program Facilities Requirements

Facility	Functions	Requirements	Remarks
Fueling and safing	Fuel with JP, LH_2, and LO_2. Drain and safety dispose of residual propellants and purge tanks. Board and debark flight crews.	200- by 300-foot concrete pad capable of supporting wheel loads. Valve pit drain line and drain pit for LO_2. Vehicle area lighting to 70 foot-candles. 4000 cubic feet at 6000-psi storage bank of GN_2 purge gas and distribution system. LH_2, LO_2, and UP trailers and transfer systems. Water deluge system serviced by 8-inch high-pressure fire maintenance. Revetted shelter and work building with water, power, and sanitation facilities. Safety showers at pad perimeters.	

Table 7-5. Horizontal Flight Test Program Facilities Requirements (Continued)

Facility	Functions	Requirements	Remarks
		Waste water treatment plant. Static ground rods and vehicle tiedowns. Work stands adjustable to 40-foot height. Personnel off-loading mobile stairs and platforms. 30-ton capacity truck crane (mobile, 100-foot boom). Payload handling load bars. Tow tractors and towbars. Parking area for 20 vehicles.	
Engine runup	Static ABES engine runs.	100- by 300-foot concrete pad capable of supporting orbiter wheel loads.	Part of safing area

Table 7-5. Horizontal Flight Test Program Facilities Requirements (Continued)

Facility	Functions	Requirements	Remarks
		Static ground rods and vehicle tiedowns.	
Compass rose	Orientation of guidance system.	190-foot radius.	Part of safing area
Runway	Takeoff and landing tests. Taxi and braking tests.	300 feet wide by 14,000 feet long. Designed for 6500-foot FAA Category II landings. Designed for orbiter landing. Portland cement concrete fixed surface. Sloped down 1 percent both directions from centerline. Surface grooved to enhance rainwater runoff and vehicle tire traction when strip is wet.	

Table 7-5. Horizontal Flight Test Program Facilities Requirements (Continued)

Facility	Functions	Requirements	Remarks
		Rigid pavement overruns 1500 feet at each end of runway. Rigid pavement shoulders 200 feet wide on each side of runway, sloped 1 percent down. Threshold bars, touchdown lights, centerline lights, and edge lights. FAA Category II control tower. Monitoring and directing equipment for VHF (air traffic, approach control, ground control), tracking radar, VOR and ILS systems, and multilateration system. Three emergency vehicle access roads and the emergency vehicles.	

Table 7-5. Horizontal Flight Test Program Facilities Requirements (Continued)

Facility	Functions	Requirements	Remarks
Taxi-ways, tow-ways and roads	Facilitate orbiter/booster and support vehicle movements.	Taxi-way between runway and fueling and safing area, 125 feet wide; 40-foot shoulders, sloped for drainage; edge lighted, with 500-foot radius on turns. Tow-ways from fueling and safing area to hangar; engine runup and compass rose facilities, 75 feet wide; 25 foot shoulders sloped for drainage, with 200-foot radius on turns. Standard vehicle roads, 15 and 25 feet wide, built to current construction standards.	
Hangar facility	Shelter from weather during storage, maintenance, and preparation.	200- by 300-foot floor; 110-foot clear height. Full opening doors at one end.	
Shops and offices	Support preparation, maintenance repair, modification and technical and program activities.	Engine shop area. Avionics shop area.	

Table 7-5. Horizontal Flight Test Program Facilities Requirements (Continued)

Facility	Functions	Requirements	Remarks
		Instrumentation shop area. Technical support facilities: calibration services, hydraulic, pneumatic, electrical laboratories. Vehicle support shops: tubing, harness, valve LO_2 clean, repair. Facilities for maintenance of facilities, SE, site, buildings. Facilities for general site services: medical, fire protection, security, graphic reproduction, communications, data processing, transportation for materials, components, and personnel. Office accommodations and equipment. Employee and visitor parking.	

Table 7-5. Horizontal Flight Test Program Facilities Requirements (Continued)

Facility	Functions	Requirements	Remarks
Data center	Receive, process, and display test data. Monitor flights.	S-band telemetry reception capability. Airborne tape playback capability. Real-time display capability, digital and analog. Direct (UHF) voice communications. Digital and analog computational capability. Miscellaneous data operational capability (D-A and A-D conversion, decommutation, etc.)	

Table 7-6 Range Support Service Requirements

Operational Activity	Support Requirements
Maintenance	Operation of calibration standards laboratory Operation of hydraulics laboratory Operation of penumatics laboratory Photographic processing Electrical power Fire protection Food services Medical service Security Propellants supply Gases and chemicals supply Communications Pest control Transportation and towing
Preflight checkout	Periodic weighings Fuel service Fire protection Medical service Meteorological services Telemetry data recording and processing Outdoor lighting Communications Transportation and towing

Table 7-6. Range Support Service Requirements (Continued)

Operational Activity	Support Requirements
Flight	Telemetry data recording, processing and display Optical and radar tracking Still and motion picture photography Pacer/chase/photo chase aircraft Flight monitoring Meteorological services Communications Air traffic control Mission control and test range coordination Crash and rescue service
Postflight	Defueling and safing Fire protection Medical services Data processing and display Outdoor lighting Communications Transportation and towing

The flight line and hangar support equipment requirements are as follows:

Low-pressure, high-volume blower (mobile)

GN_2 purge cart

Personnel off-loading stairs and platform (mobile)

Jet fuel defueler

Work stands (adjustable height)

Tow tractor and towbars

Jacks, tripod

Jacks, alligator

Hydraulic test stands

Empennage work stands (stairs and hoist, mobile)

Fuselage work stands (stairs, mobile)

Engine removal stands (jet and rocket engines)

Cabin access stairs (mobile, adjustable)

Engine maintenance stands (jet engine)

Engine transporters (jet and rocket engines)

Landing gear removal dollies

Thermal panel transport dollies

Load bar (50 feet for wing removal and installation)

Wing transport dolly

Generator test stand

Penumatic test stand

Hydraulic bench test equipment

GN_2 service cart

Engine cowling cradle

Jet engine test stand with silencer

Blast deflectors for ground runup

Jet engine starting carts

Landing gear shaft puller

Wheel and brake servicing cart

Electrical test set (mobile)

Tire mounting units (main and nose)

Miscellaneous slings and dunnage for use with facility cranes

X-ray equipment (industrial)

Motor generator (portable)